United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Paper
PNW-365

September 1986

Growth and Yield of Western Hemlock in the Pacific Northwest Following Thinning Near the Time of Initial Crown Closing

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Abstract

Hoyer, Gerald E.; Swanzy, Jon D. Growth and yield of western hemlock in the Pacific Northwest following thinning near the time of initial crown closure. Res. Pap. PNW-365. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 52 p.

Growth, stand development, and yield were studied for young, thinned western hemlock (*Tsuga heterophylla* Raf. [Sarg.]). Two similar studies were located at Cascade Head Experimental Forest in the Siuslaw National Forest, western Oregon, and near Clallam Bay on the Olympic Peninsula in Washington. At the latter, first thinnings were made at two ages; one at about the time of initial crown closure (early or crown-closure thinning), and the other after competition was well underway (late or competition thinning).

Stands, age 7 at breast height at time of crown closure thinning, were grown for 17 years at Cascade Head and for 11 years at Clallam Bay. In addition, 6 years after (early) crown-closure thinning the first (late) competition thinning was made at Clallam Bay on previously prepared, well-stocked stands. The tree spacing on the early thinnings ranged from 3 feet to 22 feet.

At ages 24 and 18 breast height on the two studies, stands with the most stocking produced the most cubic-foot volume and volume increment and the smallest average diameter. Early thinnings spaced between 7 and 12 feet produced the most usable wood in terms of Scribner board-foot volume of trees 6 inches in diameter and larger.

During the 6-year period following the late thinning, the treatments produced 55, 86, and 180 more cubic-foot volume increment per acre per year than did early thinnings that grew to the same basal area. The studies provide an approximation of the behavior of stands grown at given plantation spacings. The studies suggest that volume increment from stands thinned late differs from the volume increment of early thinning or planted stands that have attained basal area density similar to the late-thinned stands. Representative growth and yield data is provided for all treatments.

Keywords: Spacing thinnings, stand development, increment, yield (forest), western hemlock.

Summary

Western hemlock is a major timber species in western Oregon and Washington so forest managers need to understand the growth and development of hemlock stands grown from a wide range of plantation spacings. Of equal interest is behavior of stands thinned after crown closure when competition is well underway. These conditions were tested with studies in two stands, one with a site index (50-year base) of 109 feet at Cascade Head Experimental Forest, Oregon, the other with a site index of 123 feet near Clallam Bay, Washington. Both studies were age 7 at breast height (12 and 11, respectively, in terms of total age) when treatment thinnings began. Because crowns had just closed and competition had just begun, trees remaining after thinning were essentially free of competition. The trees are considered here to be nearly equivalent in growth to trees that were free to grow since stand establishment (that is, approximately equivalent to trees grown from plantation spacing). The Cascade Head study was installed in 1964, the Clallam Bay study in 1971.

The two studies were compatible but not identical. At Cascade Head, treatments included one unthinned nominal 3-foot control plot and 8-, 12-, 16-, and 20-foot, carefully selected spaced thinnings.

At Clallam Bay, basal area rather than nominal spacing distance was the plot control variable. Resulting tree spacings were a 4-foot spaced control, and nominal 7.4-, 9.2-, 12.3-, 17.6-, and 21.8-foot thinning treatments. All Clallam Bay plots were thinned to a 4.0-foot spacing distance and grown for 2 years to stabilize the stand before final treatment thinning. Six years after crown-closure thinning, selected plots growing from 4- and 7.4-foot spacings were thinned to the level of basal area reached by the 9.2-foot, spaced, crown-closure thinning.

For the study period, crown-closure thinning did not influence the average height growth of the site index trees. Ingrowth was high on the widest spacings. There has been some continuing mortality of original trees even on the widest spacings. Plots at 8-foot and closer spacings have lost trees to competition mortality. Plots at wider spacings have lost trees to other causes. Tree death from *Armillaria* root rot is serious on some treatments at Clallam Bay, probably a result of early debarking by mountain beaver of tree roots and stems near the ground.

Spacing treatments have altered tree form to the extent that tree volume is not correctly estimated by a conventional equation using tree diameter and height. A measured form factor is needed to gain volume estimation precision.

Gross current annual basal area increment reached a maximum below age 20 for the more closely spaced treatments on both studies; increment for the wider spacings did not. Gross current annual cubic-foot volume increment has not reached a maximum yet. Trees growing at spacings of 16 feet and wider have free-growing diameter increment; trees at closer spacings have some degree of diameter restriction. The closest spacings produced the most cubic-foot yield and increment. Currently, spacings between 7 and 12 feet are producing superior Scribner board-foot yields and will probably continue to do so for the immediate future.

The rapid diameter growth of trees at wide spacings has produced wood with fewer than four rings per inch of diameter. These are the central cores on which higher quality wood is now growing.

During the 6 years following cutting, the competition-thinning stands averaged 55, 86, and 180 more cubic-foot volume increment per acre per year than did the crown-closure thinning stand of the same basal area. These increases in volume increment could not be explained by differences in basal area, relative density, number of stems per acre, average diameter, or height. Something in addition is needed. Results discourage the idea that growth following competition thinning of hemlock stands is about the same as growth following crown-closure thinnings (and, by extension, plantations) of stands with the same attained basal area.

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Introduction

Early and Late Thinning in Western Hemlock

Western hemlock (*Tsuga heterophylla* Raf. [Sarg.]) is a major timber species in western Oregon and Washington, and conversion from old-growth forests to regenerated second-growth forests is well underway. These new young forests are highly productive, a fact recognized by forest managers. Managers need to know how this productivity can be altered by thinning to control tree spacing at young ages.

At almost any year during the first 25 years of a young forest stand, the manager could thin to specified distances between trees (spacing). Both the stand age and the spacing between remaining trees are subject to the manager's choice. We define two thinning ages here.

We consider "early" thinning as a thinning made at about the time of first crown closure when tree competition is just beginning; and we use the terms "early" and "crown-closure thinning" interchangeably to describe this case. Two stands, at total ages 11 and 12, that were studied for this report had early thinnings.

Trees remaining after early thinning have been nearly free growing from the time of establishment and will continue to be free growing until effects of the early thinning are gone and tree crowns close. Thus, tree growth following early thinning can be thought of as similar to growth of trees as if they had been planted at the spacing to which they have been thinned. We define "late" thinning as one made in a stand after competition is well under way. Stands older than about total age 15 are late thinnings. We use the terms "late thinning" and "competition thinning" interchangeably to describe this case.

Both early and late thinnings can be further described according to the nominal spacing distance between trees after the thinnings have been made. The plots in the studies were thinned to several different nominal tree spacings according to specific prescribed treatments in each study. A given thinning treatment can be conveniently referred to by its nominal spacing distance. Thus, "early thinning to 12 feet," and "early thinning at 12-foot spacing" describe the same treatment. We use these two terms, "thinning" and "spacing," interchangeably in this manner and consider both as treatments.

The opportunities for early and late thinning lead to questions by forest managers:

1. Does early (crown-closure) thinning to various tree spacings produce important differences in growth, yield, and product size as compared to different spacings and to nonthinned stands?

2. If stands are not thinned early at time of crown-closure, but are thinned later after competition is well underway, how do growth, yield, and product size compare with stands that were thinned at the time of crown-closure?

The purpose of this study was to answer these questions.

Results From the Literature

Results of early thinning of various tree species are common in the literature, and from this background we expected several things to occur as a result of early thinning in western hemlock. We expected individual tree basal area and volume to increase with wider spacing; we expected total cubic-volume productivity to be highest with the densest spacing, unless stagnation occurred; and because western hemlock grows well in shaded conditions, we expected no stagnation in the closer tree spacings used in the study. We expected stands grown at wider spacings would have a greater proportion of volume in trees of larger diameter.

Thinning trees to wider spacing might alter tree height in western hemlock, as Reukema (1979) found for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). Also, the diameter response to wider spacing alters the form of the tree. We expected a measurable difference in form quotient among trees grown at various spacings.

The best known plantation spacing study in the Pacific Northwest is the Wind River spacing trial for Douglas-fir located in the Wind River Experimental Forest, Gifford Pinchot National Forest, in southwestern Washington (Reukema 1979). Results from that study show the dramatic impact that early wide plantation spacing has on ultimate tree size, volume, and volume distribution. Western hemlock is known to respond well to thinning (Dilworth 1980, Malmberg 1965). We expected significant response to early thinning because of western hemlock's rapid growth and ability to respond to increased light.

Pienaar and Turnbull (1973) show that the growth and yield of thinned stands can be estimated using curve trends and inflection points from plantations (or very early spacings) grown from a range of spacing distances. Such trends along with estimates of ultimate yield are used in growth models. Stands thinned at about 10 years of age reach maximum basal area increment in the 10 years following thinning. These culmination points help estimate later growth trends as defined by the selected model. The plots in these studies were expected to help define such trends.

Materials and Methods

Two Study Areas

Two study areas were involved in the experiment. USDA Forest Service scientists installed one at the Cascade Head Experimental Forest, Siuslaw National Forest, Oregon, following the 1963 growing season; we installed the other near the town of Clallam Bay, Washington, in 1969. Design of the two studies was similar and compatible but not identical. We describe them separately in this report but combined their similar results.

The Cascade Head study had only early (crown-closure) thinning treatments and only one control plot. Standard spacing distances ranging from 7 to 20 feet were used to select the trees to leave. At Clallam Bay, on the other hand, early thinnings had a wider range of nominal spacings, from 4 to 22 feet.

The criterion for thinning at Clallam Bay was basal area; the number of stems per acre and, hence, spacing varied. In addition, Clallam Bay had several control plots as part of the experiment. We prepared all plots with a calibration thinning to 4-foot spacing and allowed plots to stabilize by growing for 2 years before the treatment thinning began. Two plots at 4-foot spacing were spaced controls. We also installed plots in an untouched area as an absolute control.

The Clallam Bay study included treatments that were not used in the Cascade Head study. At the time of the early thinning we set aside plots to be used later as a comparable late thinning. The intent was to thin late to the level of basal area reached by early crown-closure thinning treatments. Thus, early and late thinning and the growth therefrom could be directly compared on stands that were the same to begin with.

Cascade Head Study: General Description

The Cascade Head study is in the coastal hemlock zone of western Oregon (fig. 1). Plots were installed at 500 feet elevation on a nearly level site across the top of a gentle rise with slight northeast and southwest aspects. Average annual precipitation, almost all in the form of rain, is approximately 89 inches. There is frequent summer moisture from fog drip. Average annual temperature is about 50 °F.

Soils in the general area are classified as Astoria silty clay or clay loam, which are representative of the reddish-brown latosol suborder of the great soil groups. Soils have formed over tuffaceous siltstones, although basalt bedrock sometimes causes significant local modifications to the soil profile. Soil depth ranges from 2 to 6 feet. Small stones are scattered thinly through the profile. Soils are strongly acidic and humus develops rapidly. The forest floor is usually less than 2 inches thick, but the A1 horizon generally extends to 4 inches or more.

The stand used in the study had been regenerated as an experimental shelterwood cutting under an overstory stand that was logged in 1962. In 1978, increment core borings were extracted from site index sample trees that represented the upper 20 percent of plot diameter ranges. These trees were approximately 2 years older than the average stand age. There was a 4-year range among plots as well. We assigned a nominal average stand age of 12 years total and 7 years breast height for the trees at the time of the study installation in 1963 and report the same in the appendix tables. We computed average plot age by subtracting 2 years from the average age of the site index sample trees and used this in analyses where plot age was a variable.

The study included four treatments: 8-, 12-, 16- and 20-foot nominal spacings and one control plot (fig. 2). The study was a randomized block design with two blocks. A summary of average treatment statistics appears in table 1.

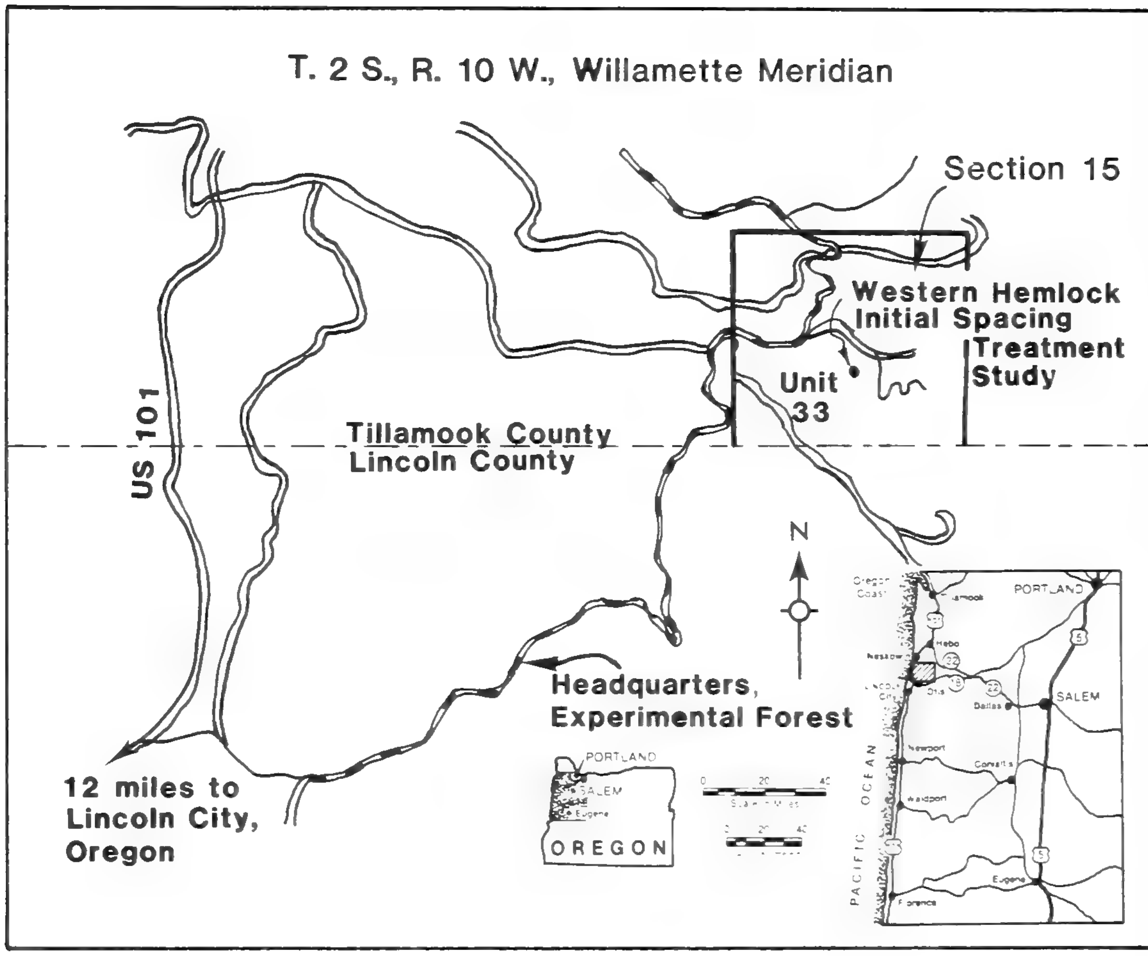

Figure 1.—Vicinity map of the western hemlock spacing treatment study at Cascade Head Experimental Forest, Oregon.

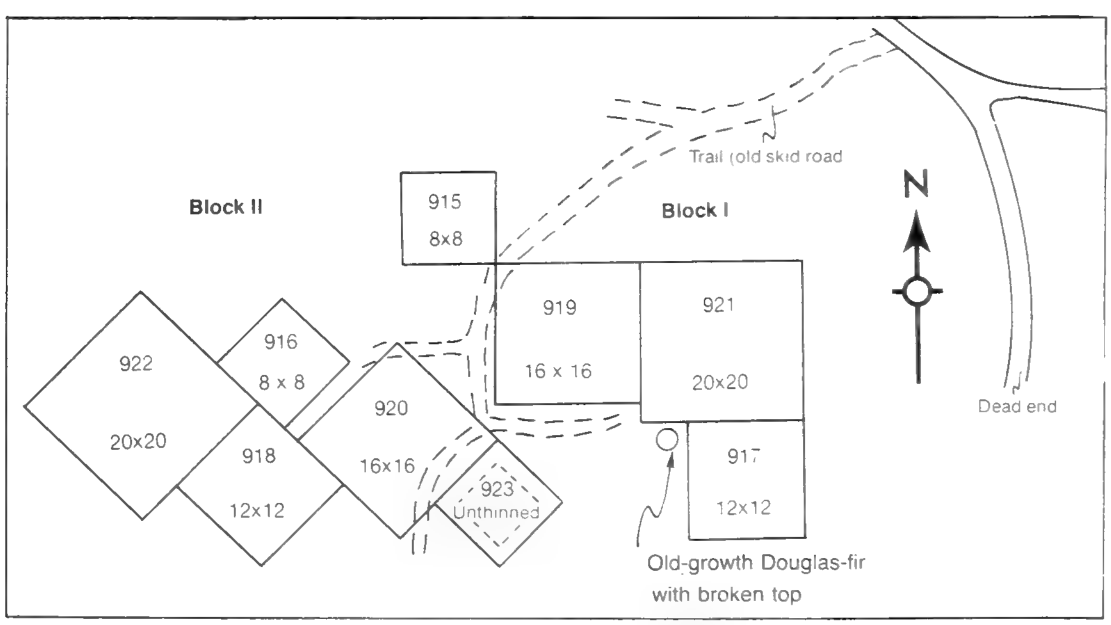

Figure 2.—Western hemlock spacing treatment plots, plot numbers, and nominal spacing in feet, Cascade Head Experimental Forest.

Table 1—Average statistics per acre, by treatment and plot, for selected years, Cascade Head, Oregon

Treatment and plot number	Site index	Height of site trees	Cubic-foot volume	Number of stems	Basal area	Mean DBH 1/	Board-foot volume 2/	1979 live crown ratio	Initial spacing	Number of stems	Basal area
	1980, total age 29								1963, total age 12		
	- - Feet - -		Thousand cubic feet		Square feet	Inches	Thousand board feet		- - - Feet - - -		Square feet
Control:											
923	122	75.9	10.6	1,201	330	7.1	23.8	0.52	3.4	4,004	115.0
8-foot spacing:											
915	114	70.9	5.3	538	179	7.8	14.0	.48	9.0	538	12.2
916	104	66.0	7.3	465	238	9.7	24.8	.56	8.9	553	13.7
Average	109	68.5	6.3	501	209	8.8	19.4	.52	9.0	546	13.0
12-foot spacing:											
917	112	67.8	4.5	278	164	10.4	16.2	.67	12.0	302	8.2
918	116	67.7	5.6	278	198	11.4	20.7	.62	12.0	302	8.1
Average	114	67.8	5.0	278	181	10.9	18.5	.64	12.0	302	8.2
16-foot spacing:											
919	111	65.5	3.5	170	129	12.0	13.7	.62	16.0	170	3.7
920	107	65.1	3.8	150	136	12.9	15.6	.66	16.0	170	5.6
Average	109	65.3	3.7	160	133	12.5	14.6	.64	16.0	170	4.6
20-foot spacing:											
921	109	65.7	2.6	109	99	12.9	10.3	.75	20.0	109	2.1
922	103	61.8	2.0	100	77	11.9	7.4	.76	20.0	109	2.0
Average	106	63.7	2.3	105	88	12.4	8.9	.76	20.0	109	2.0

1/ DBH is diameter at breast height, 4.5 feet above ground.

2/ Board-foot volume is Scribner scale to a 6-inch merchantable top diameter.

Clallam Bay: General Description

The Clallam Bay study was installed on a site at 400 feet elevation with a 15 percent slope and northeasterly aspect in the coastal western hemlock zone (fig. 3). The site faces the Strait of Juan de Fuca and is protected somewhat from the full force of Pacific Ocean storms. Average annual temperature at the weather station at the town of Clallam Bay is 48 °F and average annual precipitation is 79 inches. Soil on the site is an Ozette silt loam formed on undulating glacial till. It is 27 inches deep, is moderately well drained, and has a 9-inch A-horizon.

The study area had regenerated to a nearly pure western hemlock stand following logging. Regeneration was advanced understory trees, some newly seeded hemlock stock, and planted Douglas-fir. We removed the Douglas-fir in a subsequent treatment to produce a pure western hemlock stand.

After the 1971 growing season, we cut trees (from areas adjacent to the study plot) that were the same diameter and height as trees on the plots and counted rings at breast height and at the ground level. Based on these counts the average age of trees in the area was 7 years breast height and 11 years total. Individual plot age varied 1 year around the overall average age.

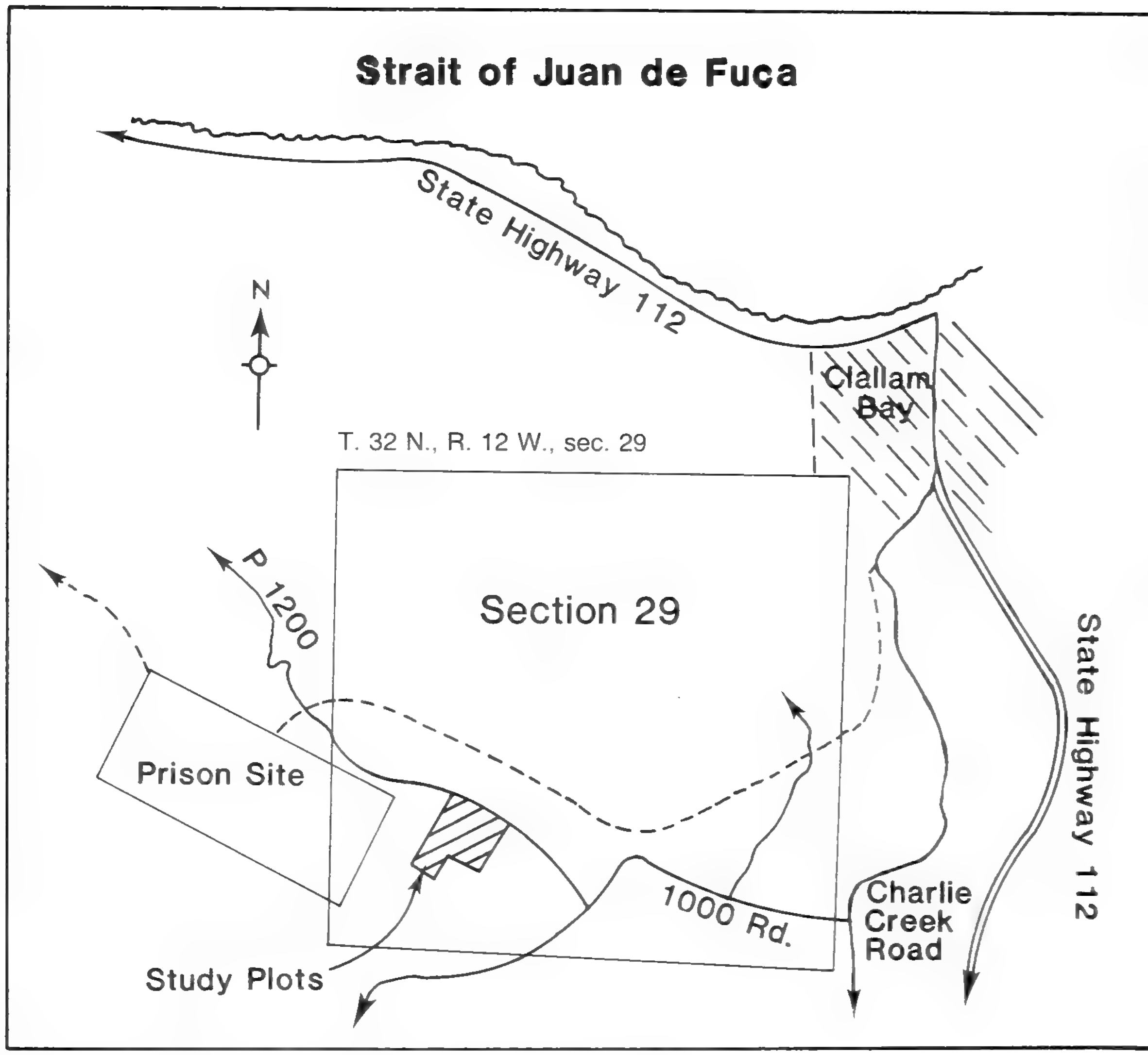

Figure 3.—Vicinity map of the western hemlock spacing treatment study near Clallam Bay, Washington.

We selected 10 treatments for study. Six of the treatments were early thinnings cut in 1971 at age 11. The other four were late thinnings to be made at specified levels of basal area. All plots were assigned completely at random within the study area.

In addition to the 10 treatments, we maintained a control area that had not been thinned in any way. The area included a few planted Douglas-fir trees. Twelve 0.005-acre plots in this control area served to describe a sparse Douglas-fir plantation with naturally regenerated hemlock. We also added a single, late-thinned plot in this control area. These plots were helpful for comparisons but were not part of the original study plan design.

The treatments, their plot numbers, and statistics at the time of early thinning in 1971 and later thinning in 1977 are summarized in table 2. Figure 4 gives spacing, plot number, and locations for all plots in the Clallam Bay study.

Table 2—Average statistics per acre, by treatment and plot, for selected years, Clallam Bay, Washington

Treatment sequence and plot number	Site index	Year	Height of site trees	Volume	Number of stems	Basal area	DBH 1/	Live crown ratio	Crown width	Number of stems	Basal area
	1977, 1982						1980			1971, age 11	
	Feet		Feet	Thousand cubic feet		Square feet	Inches		Feet		Square feet
Nonspaced control (3.5 feet)	--	1982	51.1	8.3	5,000+	370	3.6	0.46	--	5,000+	70+
Nonspaced control, released to 7.4-foot at age 17 spacing; plot 354	111	1977 before cut	-	--	5,000	271	--	--	--	--	--
	111	1977 after cut	--	.8	800	52	3.9	--	--	--	--
	111	1982	46.0	3.2	800	151	5.9	.52	--	--	--
4.0-foot spacing, plots 335 and 350	121	1982	47.6	4.8	1,569	215	4.4	.51	11	2,731	38.5
4.0-foot spacing, released to 8.0 feet at age 17; plots 352 and 353	125	1977 before cut	-	--	2,724	160	3.3	--	--	--	--
	125	1977 after cut	--	--	655	72	4.4	--	--	--	--
	125	1982	48.4	3.5	672	52	6.5	.66	--	2,604	40.4
7.4-foot spacing, plots 331, 332, 342, and 343	129	1982	50.3	4.1	687	81	6.9	.70	--	784	15.2
7.4-foot spacing, released; plots 344 and 345	127	1977 before cut	--	--	790	108	5.1	--	--	--	--
	127	1977 after cut	--	--	472	77	6.0	--	--	--	--
	127	1982	51.0	3.8	448	154	7.9	.71	--	857	15.7
9.2-foot spacing, plots 333 and 334	122	1982	46.7	2.9	394	30	7.8	.78	19	514	8.8
12.3-foot spacing, plots 336, 337, 346, 347, 348, and 349	124	1982	47.0	2.4	250	109	8.9	.77	22	287	5.1
17.6-foot spacing, plots 338 and 339	124	1982	46.8	1.5	158	69	9.8	.80	22	208	2.6
21.8-foot spacing, plots 340 and 341	121	1982	45.4	.9	83	45	9.9	.84	22	91	1.7

-- = measurements not made.

1/ DBH is diameter at breast height, 4.5 feet above the ground.

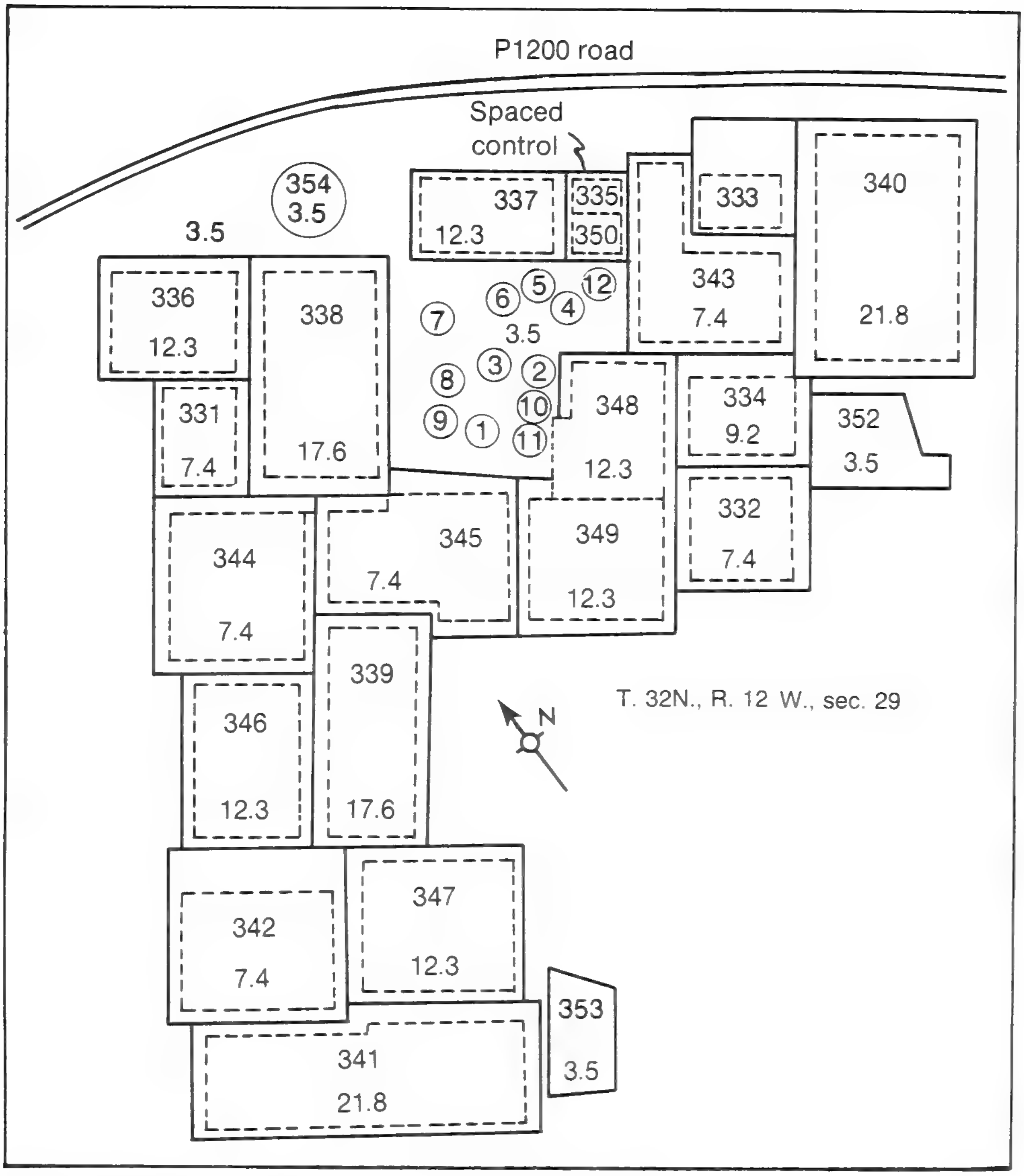

Figure 4.—Western hemlock spacing treatment plots, plot numbers, and nominal spacing in feet, Clallam Bay.

To help the reader compare details reported for the two studies, the logic used for organizing tabular data is mentioned here. The intent was to include data most likely to be directly compared either in the same table, where possible, or to place as adjacent "paired" tables, with Cascade Head appearing before Clallam Bay (examples; tables 1 through 4). Because all subjects of interest were not part of both studies, tables 5 through 10 refer only to Clallam Bay. Tables 11 and 12 each include data from both studies. In tables 13 through 22, net, live stand statistics were given by age for five units of measure, first for Cascade Head, then following in parallel order, for Clallam Bay. Next were stand increment statistics in four units of measure first for Cascade Head, then for Clallam Bay (tables 23 through 30). The final two tables (31 and 32) give stem distributions for each study.

Figure placement follows a similar logic. figures 1 through 4 give location and plot size statistics for both studies. Figures 5 through 15 illustrate various increment patterns. Figure sequence number places the same units of measure adjacent to each other for the two studies.

Tree Height

Tree height measurements, from a specifically defined sample, were used (1) as a basis to estimate the volume of all trees on the plot, and (2) as a descriptive and numerical plot variable.

We measured trees for total height every 3 to 5 years and for diameter more frequently—annually in the early years of the studies.

Volume Sample

To estimate volume, we chose a sample of at least nine trees whose heights and diameters represented the total diameter range of each plot. We computed plot volume with the tarif system (Brackett 1973, Turnbull and Hoyer 1965, Turnbull and others 1980.) In the tarif system the average tarif number of the sample trees represents the plot and identifies a specific volume-to-basal-area regression line for each plot.

We calculated average plot tarif numbers and examined averages by analysis of variance. We combined average tarif numbers by treatment and smoothed trends by year when tarif numbers were not significantly different. This procedure minimized fluctuations in volume relationships among treatments. It also permitted assigning the correct volume to trees in years when tree heights were not measured. Also, significant differences in average tarif numbers directly describe fundamental relationships among treatments and plots (Hoyer 1985). Average tarif number is a direct index to differences among plot and treatment volumes. Knowing these differences helped to interpret results. Variation among average tarif numbers can also indicate an inadequate number of sample trees or errors in measurements.

The standard volume equation used in this study was developed by Wiley and others (1978):

$$\begin{aligned} \mathrm{Ln\,CVTS} = & -6.3054647 + 2.0337286(\mathrm{Ln\,DBH}) \\ & + 1.0849(\mathrm{Ln\,H}) - 0.014978752(\mathrm{DBH})\,; \end{aligned}$$

where: DBH is diameter outside bark in inches at 4.5 feet above ground,
H is tree height in feet,
CVTS is total cubic foot volume including top and stump, and
Ln is logarithm to base e.

There was no need to use the revision of this equation, devised by Chambers and Foltz (1979), to improve accuracy at the large diameters as our trees were relatively small.

Height as a Plot Variable

The second major use of tree heights is either directly or indirectly as a plot variable. A specifically defined selection of trees and their heights is commonly the basis of site index estimation. We used the method of Wiley (1978) that defines site index as the height of the average tree at age 50 breast height for a sample of the 10 largest diameter trees from a contiguous group of 50. We selected representative trees for site index samples early in the studies and reselected later if trees no longer qualified.

We also desired a direct plot height statistic to be used as a variable in analysis. That statistic can be defined in any of several ways, usually as some segment of the tree diameter range. In this study we examined the average height of a select number of the site index trees (HT 1), the average height of the 40 largest diameter trees per acre (HT 40L, the so-called top height in European forestry), and in successive trials, the average height of the largest 20, 25, and 30 percent of the tree diameter range. The height of the largest 30 percent of the diameter range (HT 30P) had nearly the same values as HT 1, and was the most useful as a plot variable.

For most of the samples examined, a specific selection of trees at one time did not always remain a valid representation after the trees grew. Selecting the most stable portion of the stand diameter range to define the plot height statistic was an important part of preliminary analysis. Precise definition of sample tree selection varied slightly on the two studies. Details appear later.

Our use of the height of the 40 largest trees per acre, the largest 30 percent of the trees on a plot, or other similarly defined parts of the plot diameter range introduced another factor into height estimation. At most, only nine trees were measured for height on a plot. All diameter classes were not represented by a sample tree on each plot. In many years, there were no tree height measurements at all.

We directly assigned a smoothed tree height to every tree on each plot at each measurement by using the calculated volume relationship for the plot. From our volume computation procedure described earlier, we had a volume estimate for each tree. We altered the terms of the standard volume equation (Wiley and others 1978), solved for height, and assigned this height to each tree. We followed this procedure for all average height estimates except the average height of the site index trees for which we used measured sample trees. These results are summarized in tables 3 and 4.

Table 3—Average heights (HT),[1] tarif number (T),[2] and representative site index,[3] by treatment, plot number, total stand age, and year of measurement, Cascade Head, Oregon

Treatment and plot number	12 years, 1963				17 years, 1968		20 years, 1971		25 years, 1976			29 years, 1980				Site index 1980, 29 years 4/
	T	HT 1 4/	HT 40L	HT 30P	T	HT 30P	T	HT 30P	T	HT 1 4/	HT 30P	T	HT 1 4/	HT 40L	HT 30P	
	Feet															
Control:																
923	21.2	30.8a	42.1	31.4	26.0	47.9	28.8	56.4	32.7	67.7a	70.7	34.5	75.9a	81.6	76.9	122a
8-foot spacing:																
915		24.8	29.1	23.6		34.7		43.2		58.6	58.2		70.9	74.5	71.1	114
916		23.6	30.9	24.4		36.8		44.9		54.6	60.4		66.0	77.9	74.8	104
Average	19.6	24.1b	30.0	24.0	17.8	35.8	20.2	44.1	25.6	56.6b	59.3	30.9	68.5b	76.2	73.0	109b
12-foot spacing:																
917		25.6	30.1	26.1		34.2		43.7		57.1	57.7		67.8	69.9	69.3	112
918		25.4	26.7	24.7		35.2		43.9		56.0	58.5		67.7	71.3	70.2	116
Average	19.6	25.5b	28.4	25.4	16.6	34.7	19.0	43.8	23.6	56.5b	58.1	27.5	67.8b	70.6	69.8	114b
16-foot spacing:																
919		23.4	23.2	21.9		33.2		41.0		53.1	55.6		65.5	68.3	67.9	111
920		24.2	26.2	25.0		34.2		42.0		57.8	57.0		65.1	69.8	69.8	107
Average	18.3	23.8b	24.7	23.5	15.7	33.7	17.7	41.5	22.4	55.4b	56.3	26.6	65.3b	69.0	68.9	109b
20-foot spacing:																
921		24.2	20.0	20.6		31.3		38.7		53.8	53.7		65.7	64.8	65.1	109
922		21.0	20.0	20.5		31.7		38.5		50.8	52.9		61.8	63.1	64.1	103
Average	18.3	22.6c	20.0	20.6	15.0	31.5	16.7	38.6	21.4	52.3b	53.3	24.9	63.7c	63.9	64.6	106c

1/ HT 1 is from a sample of 5 largest diameter (2.4 inches) trees on each plot in 1963 and the 5 largest diameter trees on each plot in 1976 and 1980. HT 40L is the average height of the 40 largest diameter trees per acre, and HT 30P is average height of the trees in a plot that make up the top 30 percent of the diameter distribution. HT 40L and HT 30P are computed by solution of the standard volume equation, with diameter known and volume assigned by the described system.

2/ Average treatment tarif numbers (T) are the results of an analysis of variance that show significant (P=0.05) differences by year, treatment, and treatment within year.

3/ Site index is the 50-year base by Wiley (1978).

4/ Mean heights and site indexes for each given age were tested by the Duncan multiple range test. Means with the same letter were not significantly different using 0.05 probability level.

Table 4—Average heights (HT),[1/] tarif number (T),[2/] and representative site index,[3/] by treatment, plot number, and total stand age and year of measurement, Clallam Bay, Washington

Treatment and plot number	11 years, 1971				12 years, 1972		17 years, 1977				20 years, 1980				Site index 1981, 21 years 4/
	T	HT 1 4/	HT 40L	HT 30P	T	HT 30P	T	HT 1 4/	HT 40L	HT 30P	T	HT 1 4/	HT 40L	HT 30P	
	Feet														
4-foot spacing:															
335		20.4	21.7	20.0		23.2		38.2	42.4	38.6		47.6	53.0	47.2	121
350		19.6	24.1	20.0		21.8		38.3	43.8	38.4		47.7	53.3	47.7	121
Average	20.0	20.0a	22.9	20.0	20.2	22.5	22.8	38.2a	43.1	38.5	26.3	47.6b	53.2	47.5	121b
7.4-foot spacing:															
331		20.3	26.6	22.3		25.9		39.3	43.0	41.0		51.2	52.7	50.5	133
332		18.5	25.9	21.0		25.2		39.8	42.7	40.3		51.7	52.3	49.8	130
342		19.4	25.2	21.0		24.6		36.7	43.0	40.7		50.3	53.0	50.2	128
343		19.4	24.4	21.0		24.4		38.1	41.9	40.2		48.2	51.8	49.8	123
Average	19.1	19.4a	25.5	21.3	19.2	25.0	19.9	38.4a	42.6	40.6	23.1	50.3a	52.3	50.1	129a
9.2-foot spacing:															
333		18.9	22.3	19.3		22.4		35.8	40.1	37.7		45.8	48.9	47.4	119
334		19.4	25.6	21.0		24.3		38.1	40.5	38.8		47.7	49.8	48.3	125
Average	19.1	19.1a	24.0	20.2	19.1	23.4	18.6	36.8a	40.3	38.1	21.5	46.7b	49.3	47.9	122b
12.3-foot spacing:															
336		18.5	19.2	18.7		22.2		36.4	38.0	37.5		44.7	48.5	48.1	121
337		19.5	20.6	19.8		23.7		35.9	38.1	37.8		46.8	48.8	48.5	125
346		20.8	20.1	19.3		23.0		38.0	38.3	37.7		47.9	49.1	48.3	125
347		19.8	19.8	19.5		23.0		38.3	37.2	36.9		46.3	47.6	47.3	123
348		19.1	20.0	19.3		23.3		37.0	38.0	37.6		48.4	48.4	48.0	126
349		18.6	21.8	20.5		24.4		35.8	38.0	37.5		48.0	48.1	47.7	122
Average	19.1	19.2a	20.2	19.9	19.1	23.3	17.8	36.7a	37.9	37.5	20.9	47.0b	48.4	48.0	124b
17.6-foot spacing:															
338		17.9	19.4	19.4		23.3		37.0	38.2	38.2		47.1	47.0	47.0	124
339		20.3	19.9	19.9		23.5		39.6	38.0	38.0		46.4	46.1	46.8	123
Average	19.0	19.0a	19.6	19.7	19.0	23.4	17.8	38.2a	38.1	38.1	19.9	46.8b	46.5	46.9	124b
21.8-foot spacing:															
340		18.8	18.8	19.2		22.6		37.5	36.5	37.0		46.9	45.1	45.5	122
341		18.8	18.8	19.2		22.4		33.8	35.7	36.3		44.0	44.4	45.0	118
Average	18.7	18.8a	18.8	19.2	18.7	22.5	17.1	36.0a	36.1	37.7	19.3	45.4c	44.7	45.3	121b
Grand average															124

1/ HT 1 is height of carefully defined 5 largest trees per plot derived from sample tree measurements. Treatment averages were weighted according to number of trees per plot. HT 40L is height of the 40 largest diameter trees per acre, and HT 30P is the average height of the trees in a plot that made up the top 30 percent of the diameter distribution. HT 40L and HT 30P are computed by solution of the standard volume equation, with diameter known and volume assigned by the described system.

2/ Average treatment tarif numbers (T) are the results of an analysis of variance that showed significant (P=0.05) differences, by year, treatment, and treatment within a year.

3/ Site index is the 50-year base for western hemlock by Wiley (1978).

4/ Mean heights and site indexes for each given age were tested by the Duncan multiple range test. Means with the same letter were not significantly different using 0.05 probability level.

Cascade Head: Plot Design

Each plot at Cascade Head was thought of as a core of 25 study trees, a 5- by 5-tree square. Because of the stand irregularity the number of core trees actually ranged from 25 to 30 on the treated plots. In addition, there was at least one row of designated buffer trees surrounding the 25-tree core. This resulted in a 7- by 7-tree square block or 49 total trees including the buffer. The core trees were numbered and remeasured. This procedure created an isolation strip of approximately 30 feet between plots. The core trees were selected by first marking the exact spot required to meet the nominal spacing, then, for the 8-foot spacing, the largest tree within 2 feet of the ideal marked spot was accepted.

A similar procedure was followed in the 12-foot and wider spacings, except that a 4-foot-radius circle was allowed around the ideal spot. If there were no trees in these circles, the closest tree to the ideal spot was taken. Within these specifications, all locations had a tree at the start of the experiment.

Acreage assigned to each plot included the core trees plus half of the distance between the outside core tree and the next buffer tree in the nominal spacing. Because of variation in the nominal spacing, shapes of some plots were slightly rectangular rather than perfect squares. The acreage assigned to each plot therefore varied between two plots that were otherwise identical. Plot acreage and other basic plot statistics appear in table 12 in the appendix.

Cascade Head: Plot and Tree Measurements

Forest Service scientists tagged the core trees with an aluminum nail and a tree number at 4.5 feet above the ground and measured each tree for diameter and height when plots were installed. They measured trees annually for diameter and periodically for tree height in the first 15 years following installation, then measured again after a 4-year interval. In 1978, the four largest diameter trees on each plot were identified for site index measurements. In 1979, these trees were measured for height to the base of the live crown (the lowest main whorl with live branches on all four sides of the tree). This was the basis for estimating live crown ratios. In 1980, we selected six trees from the upper half of the diameter range and three from the lower half for volume assessment. When possible, we used the same trees for both site index and volume estimation.

We computed average tarif number and smoothed the trends with time, as described earlier. Average tarif numbers for selected years appear in table 3.

We selected the five largest diameter trees in the 1- to 3-inch-diameter classes on each plot in 1963 and the five largest diameter trees per plot in 1980 to represent plot height.

Clallam Bay: Plot Design

Like the Cascade Head study, plots at Clallam Bay were conceived as a core of 25 trees (with a buffer) that would be available in the future at times of critical measurement to characterize plot treatment. For plots where later thinning was planned, we selected more trees initially so there would be 25 core trees following planned thinnings. Consequently, plots selected for subsequent thinning were larger than the plots thinned at the start of the experiment. Although the design specified the plot core as squares, we used rectangles and some other geometric shapes to accommodate the limitations of the study area and still maintain required core trees within adequate buffer zones. The acreage was assigned to each plot following the procedure explained for the Cascade Head plots. Actual plot acreage is listed for each plot in table 12 in the appendix.

Two years before treatment began, we thinned the whole area, except for the nonthinned control plots, to approximately a 4-foot spacing. We increased stand uniformity by removing both very small and very large trees that were more than 2 years younger or older than the average age of the leave trees. The average leave trees were approximately 2 inches in diameter. We established some temporary plots following this calibration thinning to determine if the removal of trees over 2 inches had any effect on diameter growth of leave trees. After 2 years there was no apparent effect on leave trees; all were growing at a rate consistent with their diameter. We concluded that the 2-year period was sufficient to stabilize the stand and make all plots as uniform as possible. We then randomly selected locations for treatments, established the plots, and thinned.

We selected trees to remain on plots at the following basal area levels: 1.6, 2.5, 5, 8, and 15 square feet. The spaced control plots had 38 square feet per acre. In addition, we considered spacing and general tree vigor in balance with the target basal area. Total plot basal area was kept within 3 percent of the target basal area level prescribed in the study plan. Prior to thinning, the mean diameter of any given plot also had to be within 0.1 inch of the mean of all plots. The problem of tree selection was more difficult than it might have been because of damage by mountain beaver (*Aplodontia rufa*) to the bases of the trees. We attempted to select leave trees that had little or no basal scaring from mountain beaver. (The scope of the mountain beaver problem is reported by Hoyer and others (1979).)

Clallam Bay: Plot and Tree Measurements

We tagged the core trees with an aluminum nail and a tree number at 4.5 feet above ground and measured each tree for diameter. We selected nine volume sample trees across the range of the diameters on each plot and measured heights periodically. When the stand was older we also sampled for site index on each plot.

We anticipated a form change as a result of the various treatments and foresaw the need for a more precise volume estimating procedure that would include a measure of tree form as well as of height and diameter. We used the nine trees selected for volume sampling on representative plots and measured tree form. (We lacked these data for the Cascade Head study.) Measurements, a modification of the Hohenadl procedure (Assmann 1970, Hoyer 1985), were made of stem diameters at points on the stem proportional to total tree height. Subsequently, tree volume equations were developed that used any of several form quotients based on measurements taken at these points (Hoyer 1985). In 1983, tree form quotients were estimated on 12 to 15 trees on each plot using a wide-angle Spiegelrelaskop[1/] at diameter at breast height and points D.9, D.7, and D.5: these are, respectively, outside bark diameters at 90, 70, and 50 percent of the total tree height measured from the tip down.

Treatment changed tree stem form (Hoyer 1985), but the change did not influence the cubic-foot volume increment appreciably. To keep the two studies on the same basis, volume equations in subsequent analyses will disregard the influence of tree stem form change brought about by treatment. The exception to this is in the section discussing the study of tree form. The tarif system used for computing the volume of sample trees and plots was described earlier. Representative average tarif numbers appear in table 4.

[1/] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

We selected the seven largest trees per plot in 1971 and used the same trees again in 1977 to represent mean height, except for two trees that graphic analyses showed to be unusually larger in diameter than others in the study. Including them would have seriously inflated the height estimate for two plots. The results appear in table 4 and are identified as HT 1. In 1980, with the benefit of additional height sample trees, we calculated the height of the eight largest diameter trees per plot. These are also referred to as HT 1 in table 4.

We used four sample trees on each plot as a basis for site index estimates in 1971. We also felled and sectioned four site index trees in an adjacent, unlogged, 90-year-old stand. These together with plot site index trees gave a more meaningful pattern of height growth than did the young site index trees alone (Hoyer 1983).

In 1980, we selected up to 16 trees on each plot to update height measurements. Four of the trees on each plot qualified for site index sample trees; the others were used for tree volume (tarif) and tree form measurements.

We used the four site index sample trees as a basis for estimating the height to base of live crown and crown widths in 1980. Base of live crown was defined the same as for the Cascade Head plots and was the basis for estimating live crown ratios. Crown widths were an average of two crown diameters taken at right angles to each other from the vertical drip line of the widest branch tips. Crown width, live crown ratios, limb characteristics and characteristics of lesser vegetation were summarized (table 5) for the major early thinning treatments.

Clallam Bay: Late Competition Thinning Plots

Following the growing season in 1977, at stand age 17, we thinned two plots that had been growing at 4.0-foot spacing and two that had been growing at 7.4-foot spacing. In each case, the mean diameter of the trees following thinning was the same as the mean diameter before thinning. By 1977 the 4.0-foot spacing treatments had reached 162 square feet of basal area per acre and the 7.4-foot spacing had reached 110 square feet per acre. Both treatments had passed the culmination of current annual basal area increment.

For each treatment we chose a target basal area after thinning of 73 square feet per acre, the level that had been reached by the 9.2-foot early thinning treatment. The number of stems per acre after late thinning varied among treatments. Actual basal area attained after late thinning was 75.8 and 72.1 square feet per acre (table 20).

We selected one 0.01-acre plot in the absolute control stand (that had not received any preparatory thinning at the start of the study) and thinned it to the level of basal area attained by the early thinning to 12.3-foot spacing; that is, from 242 to 52 square feet per acre.

Thinning to the specified target basal areas allowed several interesting comparisons. Because of similar after-thinning basal area, the late competition thinnings at 4.0- and 7.4-foot spacings become directly comparable with the earlier crown-closure thinning spaced at 9.2 feet. Similarly the thinned absolute control becomes comparable with the earlier crown-closure thinning spaced at 12.3 feet.

Table 5—Evaluation of understory, by treatment and plot, with spacing and mortality (per acre), Clallam Bay, Washington

Treatment and plot	1977, ground cover	1977, limbs on bole	1980, live crown ratio	Crown widths	Number of stems		Spacing, 1971	Mortality, 1971-80	
					1971	1980		Total	Per year
				Feet			Feet	Number of trees	
Nonspaced control	--	--	0.46	--	3,437*	5,021	3.5*	No mortality; 1,584 ingrowth for 12 years.	
4.0-foot spacing, plots 335 and 350	Nothing except western hemlock seedlings and mushrooms. Scattered oxalis 1/ occurs on plot edge from side light.	Laterals often dead 6-10 feet up. Multiple overlapping layers of side branches.	.51	11	2,731	2,382	4.0	349	39
7.4-foot spacing, plots 331, 332, 342, and 343	Scattered oxalis 1/ occurs in openings.	Needles gone from interior part of lowest branches. Considerable branch overlap.	.70	--	798	729	7.4	69	7.6
9.2-foot spacing, plots 333 and 334	Deer-fern prominent; oxalis, salmonberry common. 1/	Needles to bole on lowest branches. Open sky between trees. Some branch overlap.	.78	19	513	449	9.2	14	1.5
12.3-foot spacing; plots 336, 337, 346, 347, 348, and 349	Common occurrence of annuals and perennials.	Limbs and needles to ground.	.77	22	287	263	12.3	24	2.7
17.6-foot spacing, plots 338 and 339	Same.	Same.	.80	22	140	131	17.6	9	1.0
21.8-foot spacing	Same.	Same.	.84	22	91	83	21.8	8	0.9

* = 1969 instead of 1971; -- = measurements not made.

1/ Oxalis is *Oxalis oregana* Nutt. ex T. and G.; deer-fern is *Blechnum spicant* (L.) Roth.; and salmonberry is *Rubus spectabilis* Pursh.

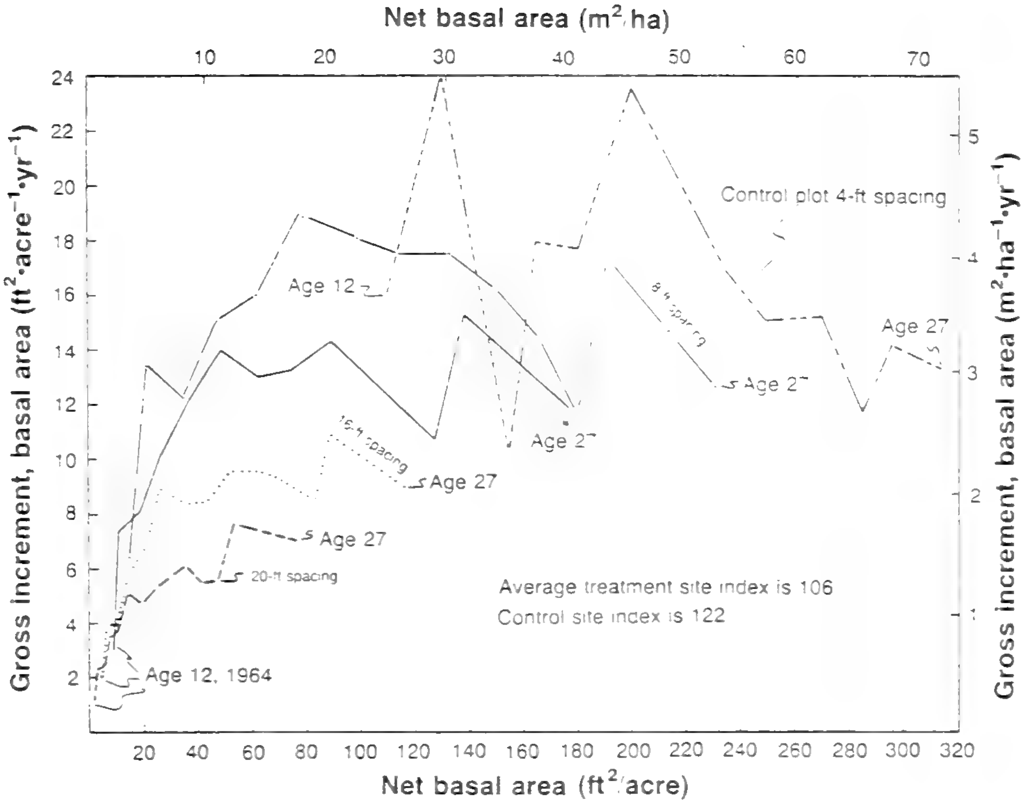

Figure 5.—Gross annual basal area increment, by level of basal area, for spacing treatments at Cascade Head.

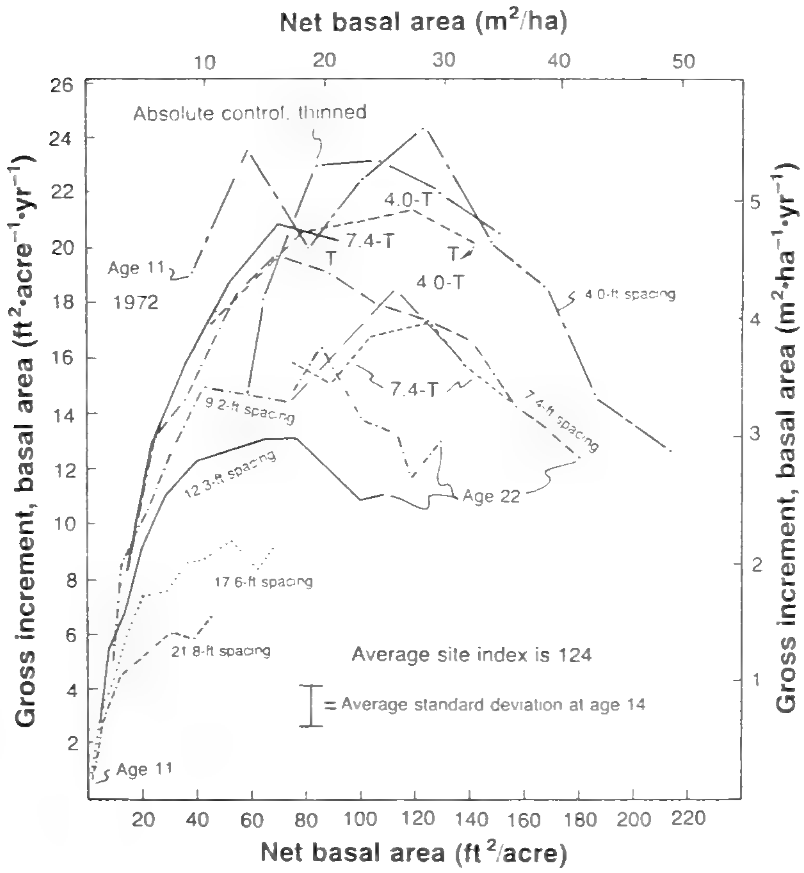

Figure 6.—Gross annual basal area increment, by level of basal area, for early and late spacing treatments at Clallam Bay.

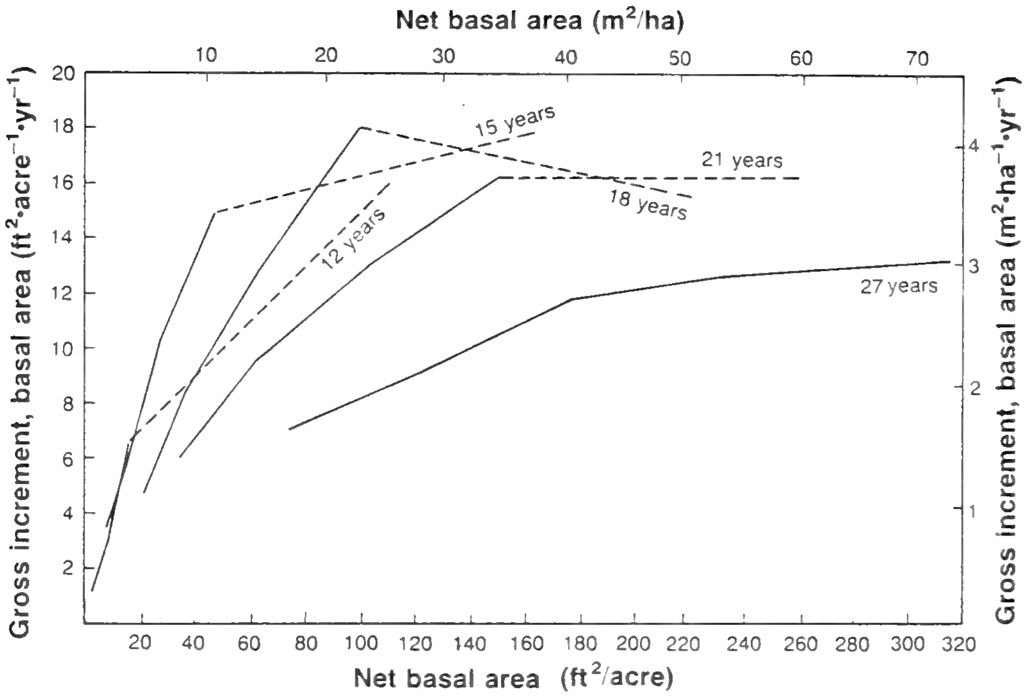

Figure 7.—Gross annual basal area increment, by level of basal area and age, for combined treatments and control plot at Cascade Head.

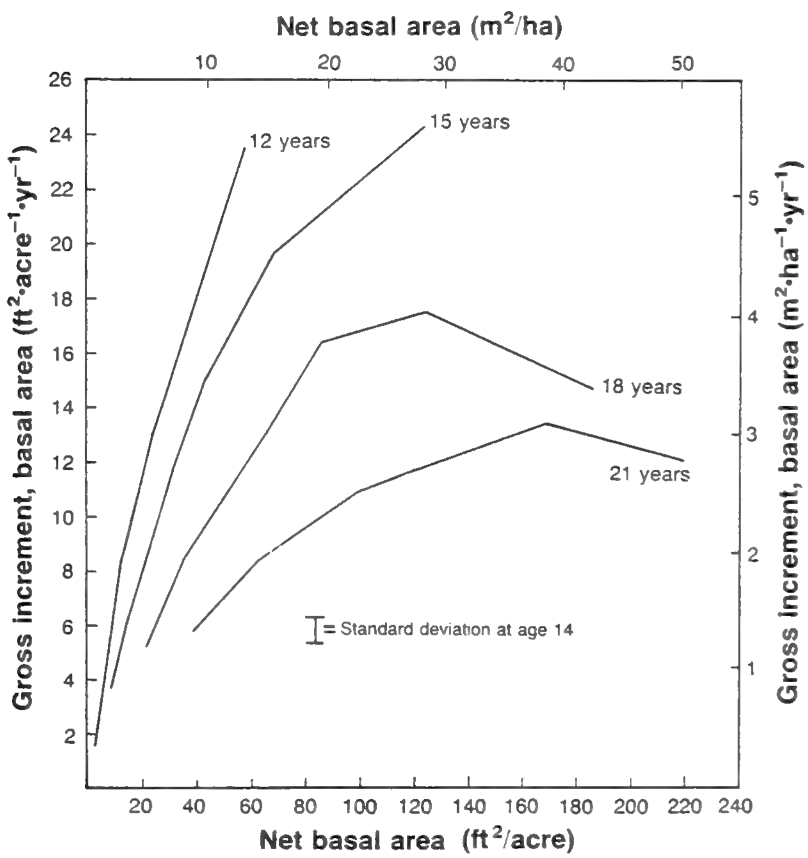

Figure 8.—Gross annual basal area increment, by level of basal area and age, for combined treatments and controls at Clallam Bay.

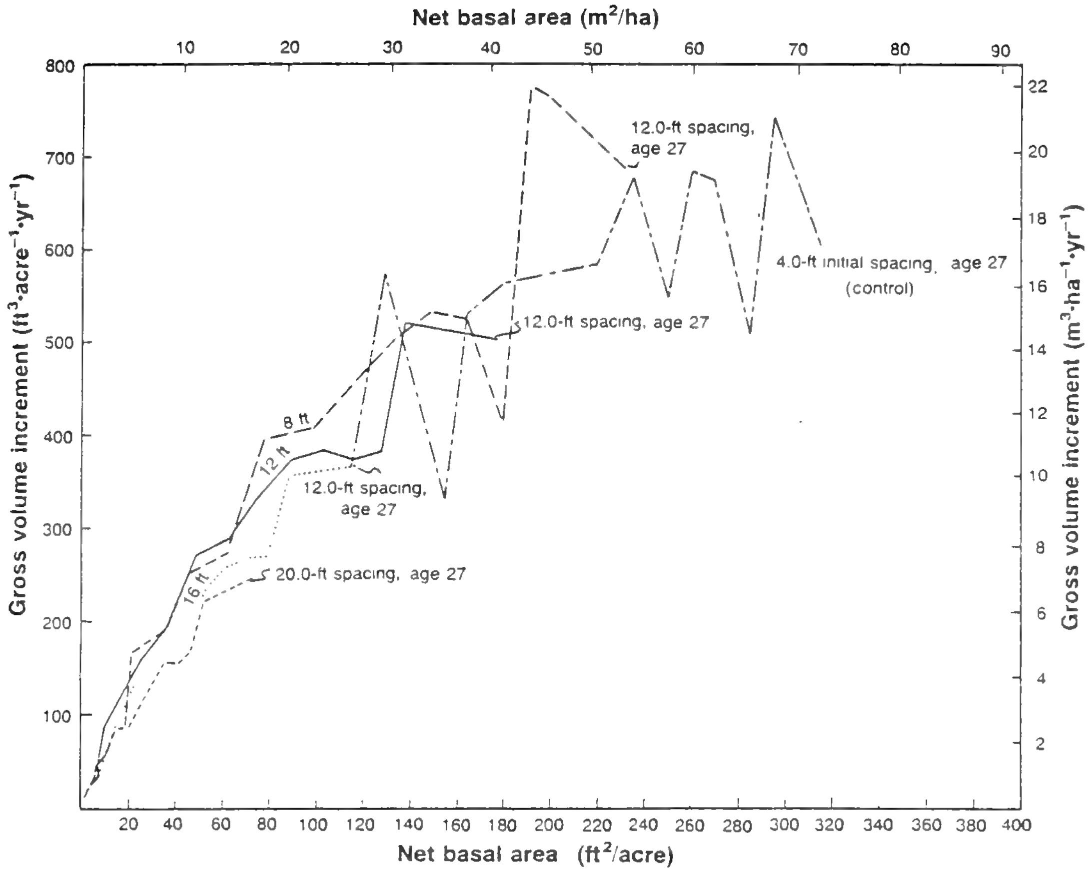

Figure 9.—Gross annual cubic-foot volume increment, by level of basal area, for spacing treatments at Cascade Head.

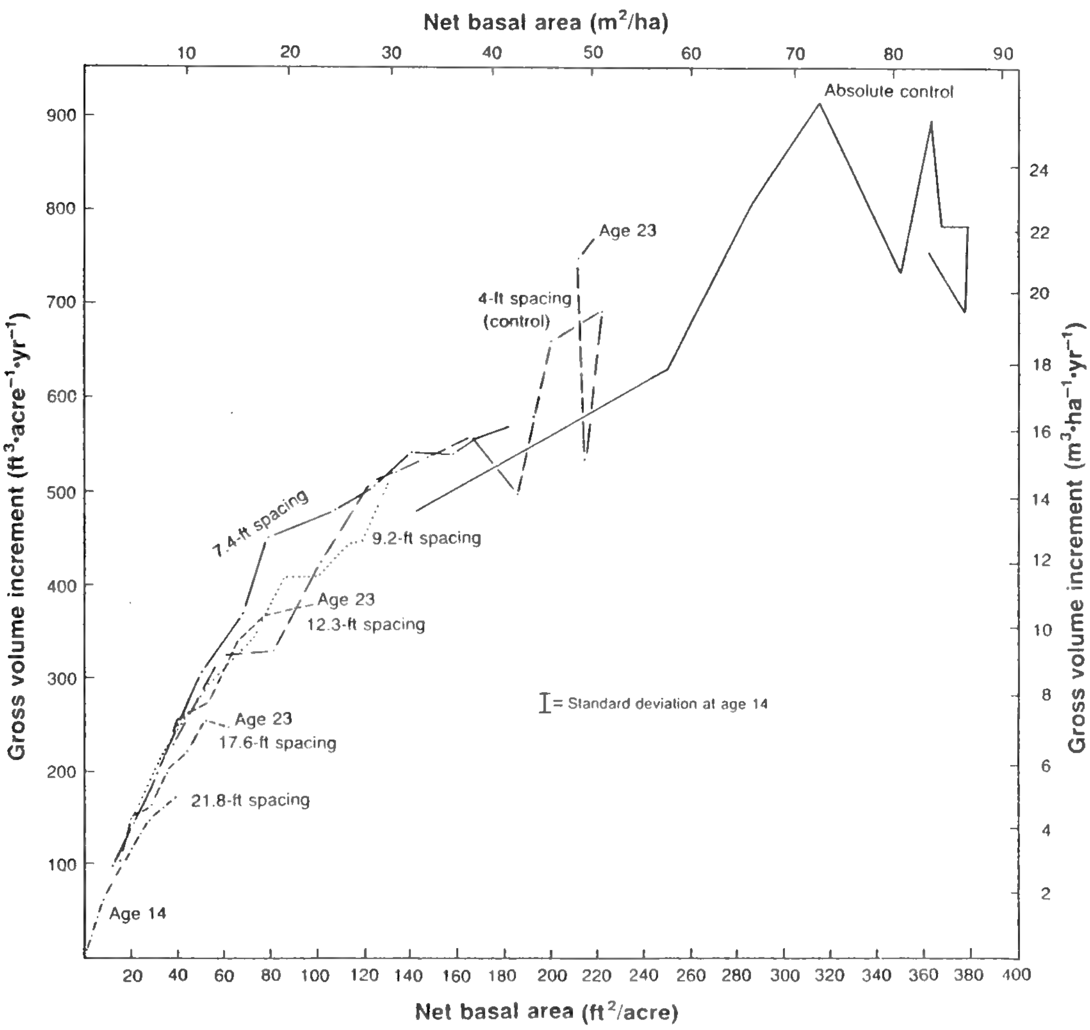

Figure 10.—Gross annual cubic-foot volume increment, by level of basal area, for spacing treatments at Clallam Bay.

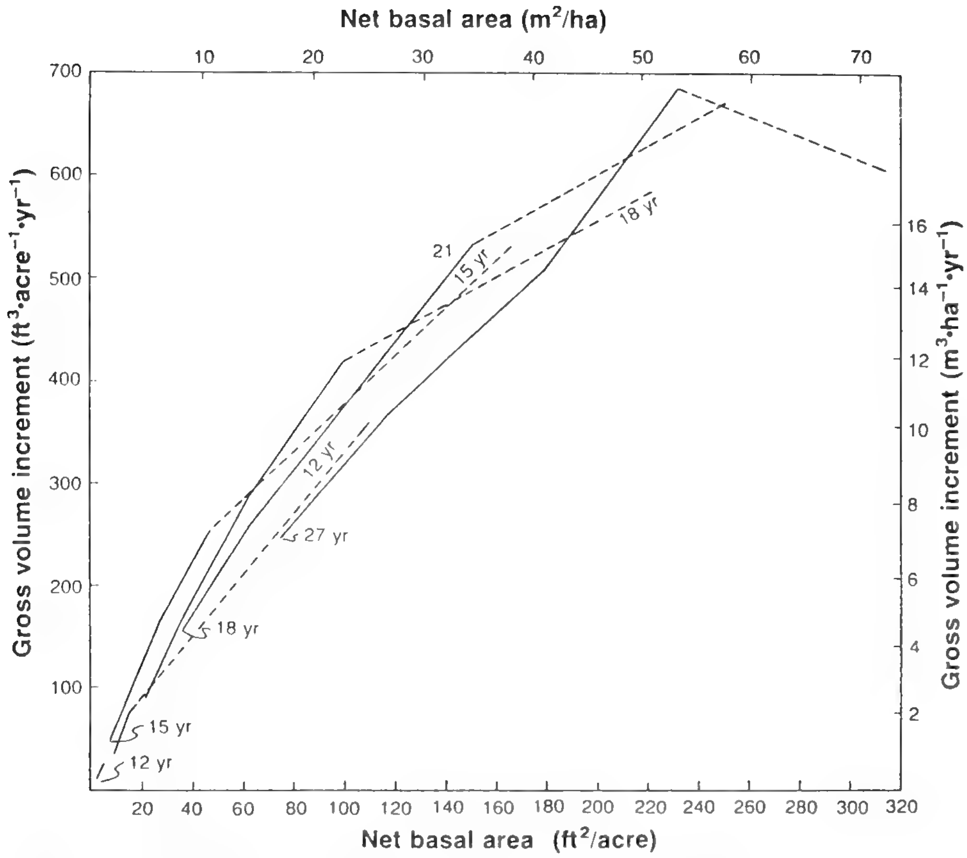

Figure 11.—Gross annual cubic-foot volume increment for combined treatments and control, by level of basal area and age, at Cascade Head.

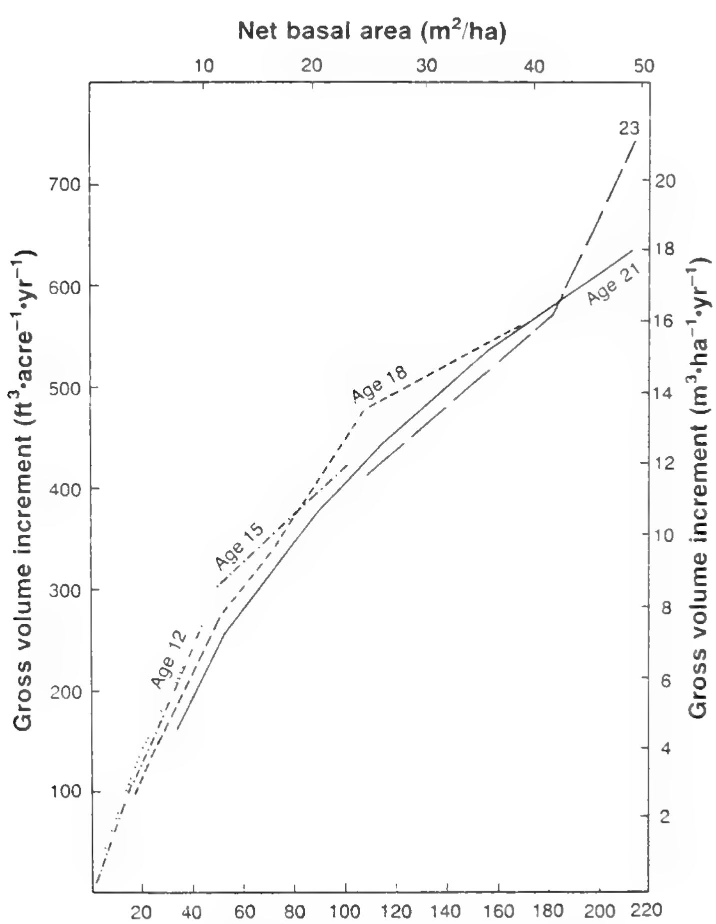

Figure 12.—Gross annual cubic-foot volume increment for combined treatments and controls, by level of basal area and age at Clallam Bay.

Figure 13.—Average diameter increment, by year, for spacing treatments at Cascade Head.

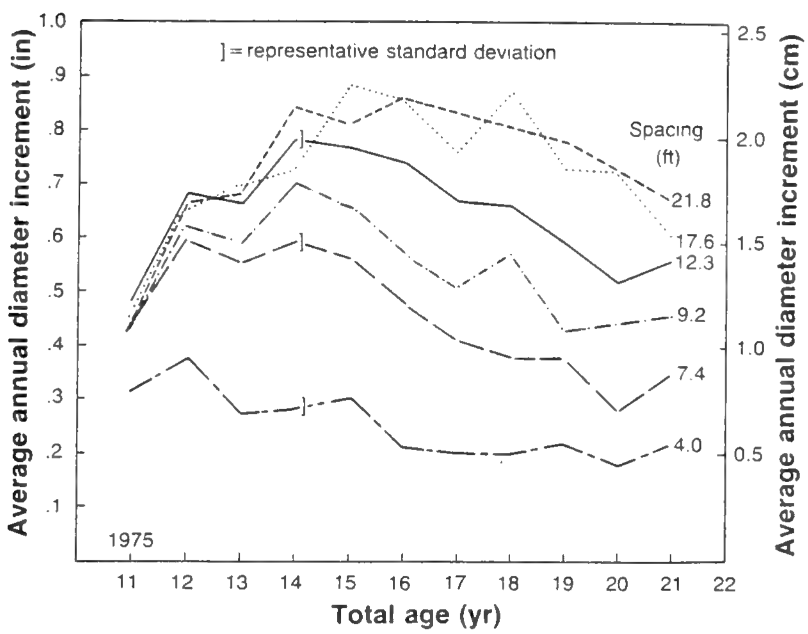

Figure 14.—Average diameter increment, by year, for spacing treatments at Clallam Bay.

Results

Results are summarized separately for the two study areas.

Cascade Head: Tarif Number, Height, and Site Index

Average plot tarif numbers differed significantly by treatments and across time according to analysis of variance tests. At the start of the experiment in 1963, the average tarif number of the 8- and 12-foot spacing treatments was 19.6; the control plot was 21.2. Differences in average tarif became more apparent in the years following study establishment; closely spaced stands developed a higher average tarif number than more widely spaced stands. This meant that there was a fundamentally different tree-volume-to-diameter relationship for the different spacings.

The average height of the five largest diameter trees on the plot (that is, the site index trees) appear as HT 1 in table 3. HT 1 differed among treatments in 1963. HT 1 of the control plots at 30.8 feet was 5 or more feet taller than the height of trees in the other treatments.

The 22.6-foot height of the widest spacing was significantly shorter than the average height of the other spaced treatments. Similar differences, significant at the 0.05 level by the Duncan multiple range test (Steel and Torrie 1980), occurred in 1976 and in 1980, the two other times when sufficient site index sample tree measurements had been made (table 3).

The average height of the 40 largest trees per acre (HT 40L) (see table 3) may be directly compared with the height of the site trees. The number of sample trees that represented the 40 largest per acre ranged from one to four within a plot, depending on plot area and spacing. The height of the 40 largest trees per acre was consistently taller on closely spaced stands than on widely spaced stands. This was true in 1963 at establishment and remained true in later years. The heights of the 40 largest trees exceeded height of the site trees by as much as 11 feet for some treatments. In other cases, HT 40L was as much as 2 to 3 feet shorter than the height of the site trees.

Height of the largest 30 percent of the plot diameter (HR 30P in table 3) behaved generally the same way as the other height estimators. HT 30P was, however, consistently closer to values of HT 1 than was the average height of the 40 largest trees.

Site index estimated by plot in 1980 at total age 29 appears in table 3. As noted earlier, site index of the control plot was significantly higher at 122 than the average of the treated plots at 109 (based on Duncan multiple range test at the 0.05 level of probability). Differences in site index among the four spacings were not statistically significant.

Cascade Head: Yields and Increment

We summarize plot height, diameter, volume, live crown ratio, and other descriptive yield statistics in table 1. Detailed plot and treatment statistics appear for seven representative stand ages in tables 13 through 17 in the appendix. Increment statistics for the same representative ages appear in tables 23 through 26 in the appendix. Average trends of basal area and volume increment appear in figures 5, 7, 9, and 11 for spacing treatment by age and level of basal area. Trends of average annual diameter increment are in figure 13. To make comparisons easy, figures for Cascade Head (odd numbers) were placed adjacent to those with the same unit of measure for Clallam Bay (even figure numbers).

Clallam Bay: Tarif Number, Height, and Site Index

Average heights of trees for Clallam Bay appear by plot and treatment in table 4. The effects of treatment on the various height estimators were similar to those for the Cascade Head Plots. The mean tarif number was significantly higher on closely spaced plots as compared to widely spaced plots.

HT 1, the height of the selected largest site index trees, was not significantly different among treatments through 1977. In 1980, the difference became statistically significant. The average height of site index trees, by treatment, for the plots at 7.4-foot spacing was highest at 50.3 feet compared with 47.6 for the 4-foot spacing and 45.4 for the 21.8-foot spacing. Average height of the site index trees for the widest spaced treatment was shorter than the average for the medium-spaced treatments, and the heights of site index trees on the 7.4-foot spacing was taller than those of the medium treatments. The height of site index trees on the 7.4-foot spacing was taller because, by chance, three of the plots had higher site indices than the average for the remainder of the treatments. The shortness of the trees in the 21.8-foot spacing was apparently not directly related to a treatment difference.

The height of the 40 largest trees per acre at Clallam Bay behaved similarly to HT 40L on the Cascade Head plots. Estimates of height for widely spaced trees were almost the same as the heights for the site index sample trees. For closely spaced trees, HT 40L exceeded the height of the site index sample trees. This was consistently true at all ages.

Height of the largest 30 percent of the trees on each plot conformed more closely to the height of the site index sample trees at the Clallam Bay plots than it did to those at the Cascade Head plots. There was no apparent relationship between height of the largest 30 percent and spacing at the Clallam Bay plots.

We examined site index on each plot in 1981. We carefully selected the eight largest diameter trees from a group of 50 contiguous trees using both plot trees and qualifying buffer zone trees. We also had estimated the site index in 1971 when the trees were only age 6 breast height. The 1971 sample, 28 trees from seven representative plots, averaged site index 129. The overall average in 1981 was 124, an apparent drop of 5 points of site index.

We examined the 1981 site index estimates (table 4) by analysis of variance and found a significant difference by the Duncan multiple range test. The differences in site index were apparently not related to spacing. The highest indices, at or near 130, were on three plots in the 7.4-foot spacing. Site indices on plots with the widest and the closest spacing were the same.

Clallam Bay: Yields and Increment

Summarized plot height, diameter, live crown ratios, and other descriptive yield statistics appear in table 2 for all treatments at age 11 (the beginning of the study) and for selected later ages. Detailed plot and treatment statistics appear in tables 18 through 22 (in the appendix) for six representative ages. Increment statistics for the same ages appear in tables 27 through 30 in the appendix.

Average trends of basal area and volume increment appear in figures 6, 8, 10, and 12 for spacing treatments by age and levels of basal area. Trends of average annual diameter increment by age and treatment spacing appear in figure 14.

Clallam Bay: Ingrowth

Ingrowth became obvious in the widely spaced treatments a few years after initial spacing. We did not measure ingrowth those years but began in 1977 at the Clallam Bay study. A summary of ingrowth since 1977 appears in table 6.

The effect of ingrowth is most striking on the two widest spaced treatments. By 1982, the number of ingrowth trees exceeded the number of trees left on the plots after original treatment and cubic-foot volume per acre of ingrowth on the 17.6-foot spacing was 19 percent of the volume of the study trees. On the 21.3-foot spacing, ingrowth volume was 77 percent of the volume of study trees. Average plot diameter of ingrowth trees in 1982 was 3 inches or less, about one-third the average diameter of original trees on the 17.6- and 21.3-foot spacing.

Mortality

In theory, the widely spaced trees will grow to a closed stand without competition mortality and then, as competition increases, some will die. In fact, however, there has been some continuing tree loss even with wide spacing. The trends of tree mortality are easily seen by tracing the number of stems per acre by year in the appendix tables. At the Cascade Head study, the equivalent of 6.4 trees per acre per year were lost in the 8-foot spacing treatment between 1973 and 1980 (table 13). Trees were in the suppressed diameter classes. The 12-foot spacing treatment lost 1.4 trees per acre per year, the 16-foot spacing treatment lost 0.8, and the 20-foot spacing treatment lost 0.26 in the 17-year period. In contrast, the 3.0-foot spacing has suffered competition mortality since the study began.

The Clallam Bay study treatments have also been losing a few trees each year. Competition mortality began in 1974 in the 4-foot control plots, which lost an average of 145 trees per acre per year in 8 years. The equivalent of this loss in cubic-foot volume is summarized in table 7. Table 7 also shows volume losses by year for the other treatments. Except for the 4.0-foot spacing, none of this loss was from competition. In each case either armillaria root rot (*Armillaria mellea* [Vahl ex Fr.] Kummer) or damage caused by mountain beaver was the primary cause of death.

Mortality influences estimates of stand increment in that either gross or net increment figures can be reported. In conventional use, gross increment is the periodic change of live trees measured at the start of a growth period even if some had died before measurement at the end of the period.

Net values of increment are the result of subtracting from the total increment, the total units of wood (not just the increment of dead trees) that had died during the period. Gross increment seems to have more meaning. In this study both gross and net figures are reported to keep numbers precisely defined. The differences between gross and net were so small that the distinction made little difference to overall trends or to interpretation of results.

Armillaria Root Rot

A summary of the impact of armillaria root rot appears in table 8. Some trees died from the disease in 1978 and others have died since. Individual plots in the 7.4- and 9.2-foot spacings were mostly seriously affected. We don't know why.

Table 6—Net accumulated ingrowth, by spacing treatment and total age, Clallam Bay, Washington[1/]

Treatment	Total age and year					
	17 1977	20 1980	22 1982	17 1977	20 1980	22 1982
Feet	Number of stems per acre			Cubic feet per acre		
4	0	0	0	0	0	0
7.4	94	102	78	37	70	80
9.2	66	95	86	19	49	73
12.3	71	86	87	15	40	56
17.6	230	490	492	41	178	278
21.3	649	1,384	1,370	86	423	712

1/ Some ingrowth occurred before measurements began in 1977. Some treatments reached peak values in years not summarized here. Mean diameter of ingrowth trees ranged from 1.5 to 3 inches for the range of years shown.

Table 7—Annual mortality, by spacing treatment and total age, Clallam Bay, Washington

Treatment	Total age and year											
	11 1971	12 1972	13 1973	14 1974	15 1975	16 1976	17 1977	18 1978	19 1979	20 1980	21 1981	22 1982
Feet	Cubic feet per acre											
4.0	--	--	--	--	--	--	--	2	1	3	114	240
4.0, thinned	--	--	--	--	--	--	1/ 1,279	--	--	--	--	10
7.4	--	--	2	2	--	1	--	12	8	7	49	17
7.4, thinned	--	2	2	--	8	2	1/ 534	31	--	--	--	14
9.2	--	4	3	6	--	--	--	25	18	--	178	8
12.3	--	--	--	1	1	--	--	8	11	4	33	41
17.6	--	--	--	--	1	--	--	--	24	--	--	3
21.3	--	--	--	--	--	--	1	--	--	--	--	--

-- = values less than 1 cubic foot.

1/ Volume removed in planned thinnings.

Table 8—Average number of trees dying from or diseased by armillaria root rot, by spacing treatment and year, Clallam Bay, Washington

Treatment and tree condition	17 1977	18 1978	19 1979	20 1980	21 1981	22 1982	Number in 1982 as percent of number in 1971
	Total age and year						
Feet	- - Accumulated number of trees per acre - -						Percent
4.0:							
Dead	--	--	--	29.0	58.0	58.0	2.1
Diseased	--	--	--	--	--	--	--
4.0, thinned:							
Dead	--	--	--	--	--	--	--
Diseased	--	--	--	--	19.0	19.0	0.7
7.4:							
Dead	--	--	--	3.2	21.9	25.4	3.2
Diseased	--	--	--	8.0	20.5	27.2	3.5
7.4, thinned:							
Dead	--	6.0	6.0	12.0	12.0	18.0	2.1
Diseased					6.0	6.0	0.7
9.2:							
Dead	--	8.0	19.5	19.5	27.5	27.5	5.3
Diseased	--	--	--	8.0	19.5	19.5	3.8
12.3:							
Dead	--	1.2	2.4	3.6	6.1	9.4	3.3
Diseased	--	--	--	3.5	9.3	11.6	4.0
17.6:							
Dead	--	--	--	--	--	2.5	1.8
Diseased	--	--	--	2.5	5.0	5.0	3.5
21.3:							
Dead	--	--	--	--	1.5	1.5	1.6
Diseased	--	--	--	1.5	1.5	1.5	1.6

-- = none.

Clallam Bay: Increment of Late Competition Thinning

Increment results appear in tables 28 through 30 in the appendix for late competition thinning treatments and their comparable alternatives. A summary of volume increment expressed as a percent of the increment of the 4.0-foot treatment appears in table 9, and figure 15 shows volume increment trends by year. Early thinning to 9.2 feet and wider spacing produced consistently less volume increment percent than did the 4.0-foot thinned control, the late thinning to 4.0-foot spacing, or the late thinning to 7.4-foot spacing. All the widely spaced early thinnings grew at less than full stocking and the increment was lower than was the increment of more fully stocked stands.

Table 9—Smoothed trends of cubic-foot volume increment percent and relative density[1/] for matched early and late thinning-treatments, Clallam Bay, Washington

Treatment	16 1976	17 1977	18 1978	19 1979	20 1980	21 1981	22 1982	23 1983	Average, 1978-83
	Total age and year								
	Percent of control volume increment								
4.0 feet	100	100	100	100	100	100	100	100	100
	2/ (462)	(510)	(549)	(583)	(612)	(639)	(656)	(671)	(618)
4.0 feet, thinned 3/	100	100	63	71	79	89	88	87	79
7.4 feet	82	86	88	88	87	87	86	86	87
7.4 feet, thinned 3/	82	86	70	76	83	92	91	91	84
9.2 feet	54	59	64	67	72	71	72	73	70
12.3 feet	42	47	52	57	59	60	58	62	58
Absolute control, 4/ thinned	--	98	51	71	86	97	106	113	87
	Relative density								
4.0 feet	82.6	91.0	98.0	102.8	106.5	107.0	101.7	97.5	102.2
4.0 feet, thinned	80.0	36.8	39.2	44.0	49.3	55.1	59.8	64.4	52.0
7.4 feet	40.8	47.2	52.8	58.0	62.6	65.8	68.9	71.9	63.3
7.4 feet, thinned	42.2	33.7	36.8	41.0	45.8	50.7	54.7	58.3	47.7
9.2 feet	26.6	31.5	35.4	39.8	43.7	43.9	46.7	49.8	43.2
12.3 feet	17.7	21.6	25.2	28.6	32.1	34.6	36.5	38.8	32.6
Absolute control, thinned	--	--	33.0	39.7	47.7	55.3	62.3	68.6	51.1

1/ Relative density is stand basal area - (mean diameter)$^{.5}$.

2/ Numbers in parentheses are cubic-foot volume increment.

3/ Thinned following the 1977 growing season to the level of basal area of 9.2-foot treatment.

4/ Thinned following the 1977 growing season to the level of basal area of 12.3-foot treatment.

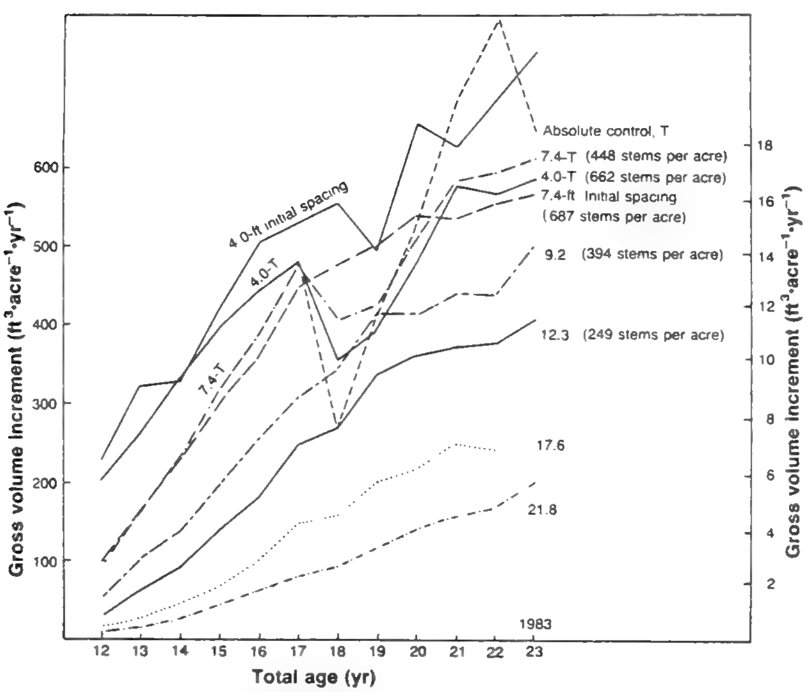

Figure 15.—Trends of volume increment by year for late thinnings (4.0 T, 7.4 T, and absolute control T), matched to the basal area level of early thinnings (9.2, 9.2, and 12.3 spacings), Clallam Bay, Washington.

The year-by-year response patterns were similar in all three late-thinned treatments. Increment response percent averaged 15 percentage points lower in the first 3 years after thinning than in the second 3 years for two of the late thinning treatments. The single absolute control plot that was thinned late also had lower response percentages in the first 3 years than in the last 3, but response in the last 3 years was unusually high and exceeded the rate of response of the 4.0-foot control. Details are in table 9.

Six-year volume increment of the two late-thinned treatments exceeded by 9 and 14 percentage points the increment of the 9.2-foot initial spacing treatment to which they had been matched by basal area level. This remained true both before and after chance differences in mortality among treatments were accounted for. The single thinned absolute control plot exceeded by 29 percentage points the increment of the 12.3-foot initial spacing to which it had been matched by basal area level. (These results, expressed as 79, 84, and 87 percent in table 9, convert to increments of 55, 86, and 180 cubic feet per acre per year of the late-thinned treatments over the early-thinned treatments to which they had been matched by basal area.) These results expressed in terms of volume increment, rather than as percentages, appear in figure 15.

Results in table 9 describe stand treatments in terms of relative density (defined as stand basal area divided by the square root of mean diameter). Relative density of the three late-thinned stands differed from that of the initial spacing stands to which they had been matched by equal basal area levels.

Clallam Bay: Tree Stem Form

Details of the procedure and results for the early years of the form study have been reported (Hoyer 1985). Resulting tree size and volume differences as of 1979 appear by treatment in table 10. Volume estimates use equations with only tree diameter and height in one case and diameter, height, and two form quotients in the other. The form quotients are D.5/D.9 (the ratio of outside bark diameter at half the total tree height, with diameter at nine-tenths of the distance from the tree top down) and D.9/DBH.

Each value for form quotient D.5/D.9 given in table 10 was significantly different from the next wider spacing except for the two widest. Test of significance was by analysis of variance and examination of confidence bands about each group mean using the 0.05 probability level. At the tree height of those sample trees the quotient D.9/DBH was a constant near the value of one and cancelled out of the equation. The data in table 10 clearly show that use of diameter and height alone, without the effect of tree form, overestimated the volume of widely spaced trees.

At the 1983 remeasurement, estimates of form quotients D.7/D.9 and D.9/DBH using the Spiegelrelaskop were significantly related to live number of stems per acre in 1982. Significance of F-value and R^2 were 95 percent and 0.22 for D.7/D.9 and 97.5 percent and 0.31 for D.9/DBH. Trends of D.7/D.9 were clearly higher (0.825) for closely spaced trees and lower (0.79) for open-grown trees. Variation was high. Values of D.9/DBH were 0.984 for closely spaced trees and 0.968 for open-grown trees.

Wood Quality, Both Studies

Number of rings per inch is one indicator of wood quality, as four rings per inch and less is not permitted in structural light framing. The faster growth material is permitted in stud grade material but the difference in price between studs and structural light framing approached $100 per thousand board feet in the 1983 market. We converted average diameter (listed by age and treatment in the appendix tables) into terms of the average number of radial rings per inch of wood (table 11).

Table 10—Volume of a tree of average diameter and height, in 1979, computed both with and without the use of smoothed, average form quotients, by spacing treatments[1/]

Treatment	Diameter	Height	Quotient D.9/DBH	Quotient D.5/D.9	Number of samples	Volume without form	Volume using form	Difference
Feet	Inches	Feet				Cubic feet	Cubic feet	Percent
4.0	3.8	42	1.00	0.725	13	1.52	1.53	0
7.4	5.9	42	1.00	.655	12	3.59	3.45	4
9.2	6.4	42	1.00	.592	17	4.21	3.77	11
17.6	7.7	42	1.00	.538	12	6.01	5.10	15
21.8	7.7	42	1.00	.538	21	6.01	5.10	15

1/ Equation without form quotients:

$$\log V = -2.71907 + 2.02478(\log DBH) - 0.0059\ DBH + 1.07716(\log H).$$

Equation with form quotients:

$$\log V = -2.53284 + 2.03622(\log DBH) - 0.0014\ DBH + 1.01277(\log H) + 1.76285(\log (D.9/DBH)) + 0.36689(\log (D.5/D.9)^2).$$

log = logarithm to base 10. D.9/DBH is the outside bark ratio of diameter at nine-tenths of tree height from tip down, to diameter at breast height. D.5/D.9 is the ratio of outside bark diameter at half height to outside bark diameter at nine-tenths of tree height.

Table 11—Number of radial rings per inch of growth on the average-sized tree, by spacing treatment and total age, Cascade Head, Oregon, and Clallam Bay, Washington

Treatment	Total age 1/ 12	14	17	20	22	27
Feet	Number of rings per inch					
Cascade Head:						
3.0 control	9.5	5.4	7.7	3.9	5.4	7.6
			average diameter under 6 inches			
				average diameter over 6 inches		
8.0	5.0	3.8	3.6	5.0	6.7	7.6
12.0	5.5	3.1	3.0	3.6	4.6	5.8
16.0	4.2	3.3	2.4	3.0	3.6	4.6
20.0	4.5	3.0	2.5	3.1	3.8	3.7
Clallam Bay:						
4.0 control	5.5	7.1	9.7	10.0	4.2	
4.0, thinned	6.7	7.4	2/ 4.8	4.7	5.6	average diameter under 6 inches
7.4	4.3	3.5	4.5	6.1	6.3	
7.4, thinned	4.5	3.5	2/ 3.9	4.1	4.4	average diameter over 6 inches
9.2	4.9	3.1	3.7	4.5	3.8	
12.3	4.2	2.8	2.8	3.6	4.2	
17.6	4.3	2.9	2.5	2.8	3.0	
21.8	4.5	2.6	2.4	2.6	2.9	

1/ Age for Clallam Bay is 11.

2/ Thinned in 1977; results only for a 1-year increase.

Live Crown Ratio, Both Studies

Live crown ratio, measured at age 28 for Cascade Head and at age 20 for Clallam Bay, appears for each initial spacing treatment in tables 1 and 2. At Cascade Head the live crown was 52 percent of total tree height on the 8-foot spacing and increased to 76 percent on the 20-foot spacing. At Clallam Bay, the 7.4-foot spacing had 70 percent live crown; the 21.8-foot spacing had 84 percent live crown.

Discussion

Site-Tree Height

Differences in spacing did not influence height of the site index tree on the plots. At the time the studies were begun and at both places, average height of the site index trees was shorter at the widest spacing than at closer spacings. The difference was statistically significant only on the Cascade Head plots and amounted to 1.5 feet in 1963 between the widest spacing and the 8-foot spacing. We suspect that in the absence of a measured tree height criteria to avoid just such a situation, there was a tendency to accept shorter than ideal trees to accomplish the widest spacing requirements. There was no way to verify this at Cascade Head. We examined the diameter distribution of the site index trees at Clallam Bay immediately after thinning in 1971, but found no conclusive evidence to support our suspicions. Bigger trees have a growth advantage over their less favored associates. Trees with a slight height advantage early in life thus tend to increase their height advantage with time. This happened in both studies. The shorter trees in the widest spaced plots grew to statistically significant shorter heights later on, as compared with the trees growing at closer spacings. This is not a vital issue as we do not expect to grow trees at such extreme spacings at these young ages, but it is worth noting.

Height of 40 Largest Trees, Both Studies

Our attempt to assign height to the 40 largest trees per acre gave unacceptable results. Estimated height of the 40 largest trees at wide spacings were nearly the same as estimated height of site trees, HT 1. At closer spacing HT 40L consistently increased and exceeded the site heights, frequently by 5 to 10 feet. This was an artifact of the estimating procedure. Two factors were involved: (1) the diameter range of selected trees varied with spacing and (2) a volume equation was used to estimate tree heights.

There were 25 trees on most of the plots, and acreage varied with spacing. One tree on a closely spaced plot, when expanded to a per acre basis, represented more trees than one tree on the larger acreage of a wider spaced plot. Therefore, on close spacings, as we selected the 40 largest trees per acre from our plot data, one diameter class (the largest) often represented 40 trees per acre. By contrast, on wide spacings several diameter classes were required to accumulate the necessary 40 trees. As a consequence, average tree height was less on wider spacings because we included smaller trees in the sample in the first years (when total width of the diameter distributions among spacings was nearly the same within a study).

As the trees at the wider spacings grew, they developed larger diameters than did trees in the closer spacings and developed different volume-to-diameter relationships; that is, different mean tarif numbers. If the increasing size of diameters was accompanied by increasing height, wider spacings would have taller trees to match the larger diameters found in later years of the study. We would not expect this to happen, nor did our estimates of HT 1 or HT 30P suggest that it occurred. Why then would our estimates of HT 40L suggest that it did? By solving the standard volume equation for tree height, with diameter and volume given, we oversimplified the relationships. The known difference

in tarif numbers among treatments implied that the standard volume equation must be adjusted to a "local volume" relationship before it is applied to a given stand. Our failure to do that ignored different volume-to-diameter relationships caused by the early spacing differences. The treatments with the highest volume-to-diameter ratios (that is, largest tarif numbers) have the tallest HT 40L per acre.

For these reasons, we did not accept HT 40L, as defined here, as a valid estimate of plot height. If a field sample of heights of the 40 largest diameter trees per acre had been drawn, their average would have been free of the artificial procedural influence. Such a sample would not be free of the diameter distribution effect brought about in these studies by our expansion of different plot areas to a per acre basis.

HT 30P

HT 30P of the trees in the top 30 percent of the diameter distribution on each plot was nearly the same as the height of the site index trees. We accepted this height estimate as a valid average plot height indicator and used it to assign plot height in years when no height measurements were made. We plan to use this statistic as a plot variable in subsequent analyses.

A logical alternative source of a plot height estimate, projected site index heights, proved less useful in a preliminary test of proposed methods. Age variance was large on the Cascade Head study and led to erratic height estimates.

Site Index

Average site index of the two studies differed—109 feet at 50 years for the treated plots at Cascade Head and 124 feet at 50 years for the Clallam Bay study area. From this we expected the yield difference visible in the growth and yield data.

The variation of site index on these relatively small plots is high. The control plot at Cascade Head—located between the two blocks of plots—exceeded, for no apparent reason, the average site index of the other plots by 13 feet. The extreme spread of site index from lowest to highest was 19 and 15 feet for Cascade Head and Clallam Bay, respectively. (With this kind of variation on study areas selected with the hope, if not the knowledge, of site uniformity, one wonders at the level of practical usefulness of site index precision much finer than 15 site index points.)

The Clallam Bay site index estimate was unstable. The 1971 estimate of 129, reduced to 124 ten years later, could be an indicator that the regional site curves do not fit the stand. We believe, however, that this is a minor aberration that may have already stabilized. Planned remeasurements will verify the correct trend.

Yields

Yields in volume and basal area were greater on early thinning treatments at close spacings than on wide ones (see appendix tables). Yield in terms of Scribner board feet for trees 6 inches in diameter and larger—a popular unit of measure that defines the most marketable component of total volume—differed by spacings. At Clallam Bay, the 7.4- through 12.3-foot early thinning spacings produced more board-foot volume by the later years than did either of the wider spacings or the 4.0-foot close spacing. In the last 10 years the early thinnings to 8- and 12-foot spacings at Cascade Head produced more board-foot volume than did the wider spacings.

In general, the early thinning to 7- through 12-foot spacings have produced, so far, the most Scribner board-foot volume. At Clallam Bay, late thinning with about 500 trees per acre produced higher Scribner board-foot volume than did early thinning with fewer trees per acre.

Basal Area Increment

Gross basal area increment appears as a time trend for each of the thinning treatment spacings plotted by levels of basal area (figs. 5 and 6). The trends are different for the two studies. At the Clallam study all but the 17.6- and 21.8-foot early thinning spacings passed the culmination of annual basal area increment. This was true for the Cascade Head study only on the 8-foot spacing and the control. The 12-, 16- and 20-foot early thinning spacings either had a flattened increment trend as basal area increased or the trend continued to rise.

Another characteristic of basal area increment is shown in figures 7 and 8 where gross basal area increment is plotted by age for levels of basal area density. Figures 7 and 8 use the same data as are used in figures 5 and 6 but the data are viewed in a different way. The level of increment for a given age at Clallam Bay was slightly higher than at Cascade Head at 60 square feet of basal area and lower.

For high levels of basal area at age 21, the stands at Cascade Head grew faster than those at Clallam Bay. The sustaining or rising growth at high levels of basal area promises higher future increment for Cascade Head than for Clallam Bay if present trends continue. We think that the most recent levels of basal area increment at the Clallam Bay study are temporarily lower than average, and we expect an increase in the future. If this is true, then projected future trends of Clallam Bay will be at higher levels than those for Cascade Head at equivalent ages. Such would be the logical results of the two studies given their relative site indices.

Volume Increment

Gross volume increment trends appear in figures 9 and 10 by levels of basal area for each early thinning treatment through time. The control plot at Cascade Head appeared to reach a maximum current annual increment at 600 cubic feet per acre per year at 26 years and at 300 square feet of basal area. This exceeded the approximate maximum of 420 cubic feet per acre current annual increment estimated for the equivalent site index (Barnes 1962). This apparent maximum may be only a temporary level in a continuing upward trend.

The 4-foot control at Clallam Bay did not reach a maximum volume increment. The increments of the 7.4-, 9.2-, and 12.3-foot early thinning spacings did appear, however, to reach increment maxima. This occurred from ages 20 to 22 and was an unexpected result at such low ages. We assume these apparent increment maxima are temporary downturns of an otherwise steadily increasing increment trend.

Trends of volume increment by levels of basal area for selected ages appear in figures 11 and 12. Increment for the same ages was slightly although not consistently higher on the Clallam Bay study than on the (lower site index) Cascade Head study.

Diameter Increment

As expected, trees grown at wider spacings produced larger average diameters than did trees grown at closer spacings. At Cascade Head mean diameter of stands at the 20-foot spacing treatment exceeded the diameter of the 3.0-foot (control) treatment by 5.3 inches at age 29, 17 years after initial thinning. At Clallam Bay, mean diameter of thinnings to 21.8-foot spacing exceeded mean diameter of the 4.0-foot (control) spacing by 5.5 inches at age 22, 11 years after early thinning treatment.

Figures 13 and 14 show the trends of average diameter increment by early thinning treatment and by year for the two studies. In each study the two widest spacings had similar overlapping trends, indicating the increment was that of free-growing trees. By age 24 on the Cascade Head study, the trend of the 16-foot spacing reached a level between that of the 12- and 20-foot spacings; this trend indicated that the 16-foot spacing diameter increment was influenced by competition. A similar sorting of trends may be beginning in the last 3 years of the Clallam Bay study.

Ingrowth

Ingrowth, especially on the widely spaced treatments, increased the total cubic-foot volume, at least temporarily. Tree sizes were small, averaging 3 inches in diameter or less, and most are unlikely to become important to stands in the near future. We expect most ingrowth trees will eventually die as the main crown canopy closes. Presence of ingrowth trees confounds plot statistics, especially averages based on number of trees per unit area. This fact was sufficient justification in this study to exclude ingrowth trees from major consideration.

Mortality

The annual mortality loss to armillaria root rot was disturbing when well-spaced trees died on the thinned stands. Loss was high enough on two individual plots that, if it continues, future usefulness of the plots is questionable. The average of 5.3 percent of trees dying in 11 years (treatment 9.2, table 8), if projected to a 60-year rotation, would be 20 percent of the stand—an excessive amount. The present high number of diseased trees suggests that high mortality may continue. On the other hand, 2.1 percent of control plot trees dying in 11 years does not seem excessive. We believe that there is more armillaria root rot than normal on the thinned treatments, not necessarily because of thinning, but because of the unusual high basal damage to trees by mountain beaver.

Late Thinning at Clallam Bay

The pattern of increased increment following late thinning seems consistent in spite of the small size of the single plot thinned in the absolute control. All three late thinnings grew more cubic-foot volume increment than the early thinnings to which they were matched by level of basal area. The hypothesis that volume increment of late thinnings can be estimated by increment from stands thinned early that have reached the same level of basal area does not hold for hemlock for the 6 years examined. Nor does it hold consistently for basal area increment as examination of figure 6 verifies. This suggests that past modeling efforts to estimate thinned stand response, as equivalent to the response from stands of the same basal area that were thinned early, have underestimated hemlock growth.

There were no apparent differences in tree height growth that would help explain the volume increment differences between the early and late thinnings. Difference in form was not examined as a possible influence.

Basal area is not a sufficiently sensitive index of growing stock to distinguish increment of thinned from nonthinned stands. As shown in table 9, relative density failed to help explain the differences in volume increment. We examined the number of stems per acre, mean diameter, and the expression, "D times height-to-base-of-live-crown," as an estimator of cambium surface area. None were any better than relative density for explaining the volume increment behavior.

We do not know if the increased increment is a permanent shift of the increment trend or only a temporary change. It is important to find out.

The pattern of relatively low volume increment response for 3 years followed by relatively higher increment the next 3 years on all three late thinnings conforms to short-term reactions to thinning as described by Bradley (1963). The generally higher increment rate on the absolute control over the other two late thinnings may relate to the difference in diameter classes left after the late thinning. Note in table 31 that in the absolute control plot, half of the trees left were in the largest single diameter class that existed before thinning. By contrast, for the other two thinnings where the average diameter of trees cut equaled that of trees prior to cutting, the largest of the hemlock trees came from a wider portion of the diameter distribution. The same basal area could have been left on few trees of larger diameter with greater vigor and ability to respond. Had that been the method of tree selection at thinning, the volume response from the more vigorous trees might have been greater.

Effect of Form Difference on Volume Increment

Tree form was significantly influenced by early thinning treatments. A measured form quotient was required to discern differences in volume that remained hidden if tree diameter and height alone were the basis for volume estimation. The amount of volume error seemed to increase as stands aged, an important point to verify in future remeasurements. So far, failure to include a form quotient when estimating volume has not materially influenced interpretation of volume increment results.

Wood Quality, Both Studies

After a stand reaches 6 inches average diameter, the trees begin to grow into sizes valuable for sawn wood production. The time required to reach 6 inches is an indicator of useful wood production.

By age 20, the average diameter of most of the early thinning treatments in both studies reached 6 inches. In the two widest spacings on the higher site at Clallam Bay, the 6-inch average diameter was reached by age 17.

The rate at which wood grows, expressed as the number of rings per inch of wood, is an indicator of wood quality.

At age 20 there were less than four rings per inch in the 12-foot and wider spacings. By age 27 at the Cascade Head study, all early thinning treatments except the 20-foot spacing were growing at more than four rings per inch. It appears that few of the treatments will be growing trees with excessive rings per inch. This is important now because the stands have crossed the 6-inch diameter threshold into a period of wood value growth. The wider ringed central core of wood already established is the base on which better quality is being added.

There is doubt about the sensitivity of rings per inch of the average tree as an index to stand wood quality. Trees larger than stand average are the most dynamic part of the stand and grow faster than average. For this reason, the subject warrants further examination.

Acknowledgments

We appreciate the climate of cooperation created by the two public agencies, the USDA Forest Service through the Pacific Northwest Research Station and Washington State Department of Natural Resources. We also appreciate the program managers who had the vision to support the kind of work described in this report. Long-term studies such as these are impossible without continuing cooperation and support.

We acknowledge the contribution to this study by Francis Herman (USDA Forest Service, retired) who had the foresight to design and install the Cascade Head early thinning study plots and by Jack Booth (USDA Forest Service) who remeasured and tended the plots for so many years. Norman A. Andersen (Washington State Department of Natural Resources) supervised all the remeasurements of the Clallam Bay study plots and was responsible for the flow of all data from field remeasurements into computer form, through editing, and to initial plot summarization.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 acre = 0.404686 hectare
1 square foot = 0.092903 square meter
1 cubic foot = 0.028316 cubic meter
1 square foot per acre = 0.229568 square meter per hectare
1 cubic foot per acre = 0.69972 cubic meter per hectare
°F = (9/5 °C) + 32

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Appendix

Table 12—Plot number, spacing, acreage, and number of trees per acre, by plot, Cascade Head, Oregon, and Clallam Bay, Washington

Location and plot number	Spacing of trees	Size of plot		Number of trees per acre
	---- Feet -----		Acre	
Cascade Head:				
923	3	29.5x29.5	0.01998	4,104
915	8	44x46	.04646	581
916	8	44x48	.04518	664
917	12	60x60	.08264	302
918	12	60x60	.08264	351
919	16	80x80	.14692	177
920	16	80x80	.14692	170
921	20	100x100	.22957	109
922	20	100x100	.22957	109
Clallam Bay:				
335	4	25x30	.01721	2,615
350	4	25x30	.01722	2,842
352	4	--	.070045	2,327
353	4	--	.0416529	2,881
331	7.4	60x60	.08264	787
332	7.4	48x72	.07934	781
342	7.4	85x66	.12879	815
343	7.4	--	.15538	753
344	7.4	86.8x86.8	.17296	815
345	7.4	--	.16262	898
333	9.2	40x48	.04077	567
334	9.2	39x68	.06088	460
336	12.3	75.6x61.5	.10673	309
337	12.3	72x48	.07934	277
346	12.3	91.7x71	.14947	308
347	12.3	69x86	.13623	279
348	12.3	--	.13652	271
349	12.3	--	.17716	280
338	17.6	69.6x121.8	.19461	144
339	17.6	52.2x121.8	.14596	137
340	21.8	88x154	.3111	90
341	21.8	--	.29439	92

-- = irregularly shaped plots, see figure 4.

Table 13—Number of stems per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Number per acre						
3	923	4,004	3,754	3,053	2,603	1,852	1,502	1,201
8	915	581	581	581	581	581	581	581
	916	664	664	664	664	664	620	575
Average		623	623	623	623	623	600	578
12	917	302	302	302	278	278	278	278
	918	351	339	339	339	339	327	327
Average		327	321	321	309	309	302	302
16	919	177	177	177	170	170	170	170
	920	170	150	150	150	150	150	150
Average		174	163	163	160	160	160	160
20	921	109	109	109	109	109	109	109
	922	109	104	100	100	100	100	100
Average		109	107	104	104	104	104	104

Table 14—Diameter at breast height, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Inches						
3	923	2.29	2.75	3.47	4.20	5.17	6.05	7.10
8	915	2.07	3.10	4.59	6.02	6.70	7.49	8.25
	916	2.10	3.28	4.95	6.41	7.22	8.37	9.71
Average		2.09	3.19	4.77	6.22	6.96	7.93	8.98
12	917	2.23	3.21	4.87	6.86	7.86	9.02	10.4
	918	2.22	3.35	5.66	7.58	8.66	10.15	11.53
Average		2.23	3.28	5.27	7.22	8.26	9.59	10.97
16	919	1.98	3.19	5.39	7.60	8.83	10.38	11.98
	920	2.46	3.67	5.65	7.92	9.27	11.02	12.92
Average		2.22	3.43	5.52	7.76	9.05	10.70	12.45
20	921	1.88	2.99	5.21	7.53	8.90	10.76	12.93
	922	1.84	3.08	5.04	6.94	8.17	9.72	11.89
Average		1.86	3.04	5.13	7.24	8.54	10.24	12.41

Table 15—Net basal area per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Square feet						
3	923	115.0	155.2	200.2	210.2	270.2	300.3	330.3
8	915	13.6	30.5	66.8	115.0	142.3	178.0	215.7
	916	16.0	38.9	88.7	148.9	189.0	237.1	295.7
Average		14.8	34.7	77.8	132.0	165.7	207.6	255.7
12	917	8.2	17.0	39.2	71.5	93.7	123.5	164.3
	918	9.4	20.7	59.1	106.3	138.6	183.6	236.9
Average		8.8	18.9	49.2	88.9	116.2	153.6	200.6
16	919	3.8	9.8	28.0	53.6	72.4	100.1	133.2
	920	5.6	11.0	26.1	51.2	70.1	99.2	136.2
Average		4.7	10.4	27.1	52.4	71.3	99.7	134.7
20	921	2.1	5.3	16.1	33.7	47.0	68.8	99.3
	922	2.0	5.4	13.9	26.3	36.5	51.6	77.3
Average		2.1	5.4	15.0	30.0	41.8	60.2	88.3

Table 16—Total net yield in cubic-foot volume, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Cubic feet						
3	923	1,496	2,432	3,859	5,861	7,002	8,669	10,580
8	915	132	328	936	2,042	2,886	4,317	6,464
	916	157	439	1,297	2,713	3,932	5,901	9,124
Average		145	384	1,117	2,378	3,409	5,109	7,794
12	917	88	195	534	1,248	1,857	2,867	4,563
	918	88	230	837	1,901	2,803	4,343	6,668
Average		88	213	686	1,575	2,330	3,288	5,616
16	919	33	100	370	890	1,383	2,256	3,654
	920	53	121	354	863	1,356	2,266	3,801
Average		43	111	362	877	1,370	2,261	3,728
20	921	17	50	200	526	852	1,492	2,580
	922	16	52	171	403	651	1,097	1,983
Average		17	51	186	465	752	1,295	2,281

Table 17—Net Scribner board-foot volume per acre, trees 6 inches and larger, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
		Total age and year						
Feet		Board feet						
3	923	0	160	1,451	4,324	7,497	13,564	23,784
8	915	0	0	214	2,154	4,567	9,862	18,885
	916	0	0	559	3,794	7,938	15,900	31,072
Average		0	0	387	2,974	6,253	12,881	24,979
12	917	0	0	263	1,873	3,974	8,095	16,245
	918	0	0	424	3,339	6,748	13,540	25,079
Average		0	0	344	2,606	5,361	10,818	20,662
16	919	0	0	174	1,445	3,243	7,112	14,063
	920	0	0	236	1,750	3,705	7,822	15,604
Average		0	0	205	1,598	3,474	7,467	14,834
20	921	0	0	60	818	2,041	4,857	10,304
	922	0	0	67	528	1,335	3,161	7,449
Average		0	0	64	673	1,688	4,009	8,876

Table 18—Number of stems per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

		Total age and year					
Spacing treatment	Plot number	11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Number per acre					
4.0	335	2,615	2,615	2,615	2,499	2,208	1,453
	350	2,847	2,847	2,847	2,847	2,557	1,685
Average		2,731	2,731	2,731	2,673	2,383	1,569
4.0, T	352	2,342	2,342	2,384	691	671	657
	353	2,881	2,881	3,025	672	672	672
Average		2,612	2,612	2,705	2,724/682*	672	662
7.4	331	787	787	762	750	726	714
	332	781	769	769	769	744	718
	342	815	815	784	777	753	652
	343	753	734	708	708	695	663
Average		784	776	756	751	730	687
7.4, T	344	815	798	769	451	434	428
	345	898	849	843	492	467	467
Average		857	824	806	790/472*	451	448
9.2	333	567	545	545	545	522	476
	334	460	460	394	394	378	312
Average		514	503	470	470	462	394
12.3	336	309	309	309	300	300	281
	337	277	277	265	265	265	252
	346	308	301	288	281	261	228
	347	279	272	272	272	272	257
	348	271	264	256	249	227	205
	349	280	280	280	280	280	268
Average		287	284	278	276	268	249
17.6	338	144	144	144	139	139	134
	339	137	137	137	137	123	123
Average		141	141	141	138	131	129
21.8	340	90	90	84	84	84	84
	341	92	88	85	82	82	82
Average		91	89	85	83	83	83

* = before/after thinning; T = thinned.

Table 19—Diameter at breast height, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year: 11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Inches					
4.0	335	1.74	2.12	2.74	3.50	4.16	4.52
	350	1.47	1.81	2.48	3.29	3.88	4.32
Average		1.61	1.97	2.61	3.40	4.02	4.42
4.0, T	352	1.72	2.04	2.66	4.44	5.63	6.40
	353	1.79	2.06	2.55	4.43	5.69	6.55
Average		1.75	2.05	2.61	4.44*	5.66	6.48
7.4	331	1.92	2.36	3.52	5.17	6.40	7.01
	332	1.86	2.37	3.46	4.99	6.05	6.67
	342	1.87	2.29	3.44	5.09	6.21	6.87
	343	1.89	2.34	3.50	5.18	6.46	7.07
Average		1.89	2.34	3.48	5.11	6.28	6.91
7.4, T	344	1.84	2.30	3.49	5.25	7.13	8.00
	345	1.82	2.25	3.34	4.89	6.94	7.83
Average		1.83	2.28	3.42	5.07*	7.04	7.92
9.2	333	1.71	2.12	3.37	5.20	6.68	7.52
	334	1.85	2.29	3.47	5.50	7.03	7.97
Average		1.78	2.21	3.42	5.35	6.86	7.75
12.3	336	1.74	2.25	3.71	6.17	8.22	9.38
	337	1.84	2.32	3.66	5.93	7.97	9.23
	346	1.78	2.24	3.59	6.00	7.97	8.94
	347	1.83	2.29	3.56	5.69	7.41	8.39
	348	1.84	2.37	3.76	6.08	8.05	9.13
	349	1.83	2.26	3.52	5.62	7.42	8.44
Average		1.81	2.29	3.63	5.92	7.84	8.92
17.6	338	1.82	2.28	3.64	6.14	8.48	9.77
	339	1.87	2.34	3.68	6.10	8.47	9.84
Average		1.85	2.31	3.66	6.12	8.48	9.81
21.8	340	1.81	2.26	3.70	6.25	8.72	10.25
	341	1.84	2.28	3.51	5.98	8.34	9.60
Average		1.83	2.27	3.61	6.12	8.53	9.93

* = after thinning; T = thinned.

Table 20—Net basal area per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year					
		11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Square feet					
4.0	335	43.3	63.9	106.7	167.3	208.2	202.9
	350	33.7	51.0	95.3	168.2	218.8	224.6
Average		38.5	57.5	101.0	167.8	213.5	213.8
4.0, T	352	37.7	53.4	91.7	72.3	116.2	146.9
	353	49.3	66.9	107.5	71.9	118.6	157.1
Average		43.5	60.2	99.6	162/72.1*	117.4	152.0
7.4	331	15.9	24.0	52.7	109.3	162.0	191.6
	332	14.8	23.9	50.3	104.4	149.3	174.0
	342	15.5	23.4	51.2	109.6	158.5	175.8
	343	14.7	22.4	47.8	103.8	158.0	182.5
Average		15.2	23.4	50.5	106.8	157.0	181.0
7.4, T	344	15.1	23.2	51.5	76.1	120.2	151.6
	345	16.3	24.3	51.4	75.5	122.8	156.2
Average		15.7	23.8	51.5	110/75.8*	121.5	153.9
9.2	333	9.0	13.4	33.8	80.4	127.0	146.8
	334	8.6	13.2	27.6	65.1	102.0	113.2
Average		8.8	13.3	30.7	72.8	114.5	130.0
12.3	336	5.1	8.5	23.2	62.3	110.5	134.9
	337	5.1	8.1	20.1	50.9	91.8	117.0
	346	5.3	8.4	20.8	55.1	91.4	102.8
	347	5.1	7.9	18.8	48.0	81.4	98.7
	348	5.0	8.2	20.1	50.2	80.3	94.4
	349	5.1	7.8	18.9	48.3	84.0	105.5
Average		5.1	8.2	20.3	52.5	89.9	108.9
17.6	338	2.6	4.1	10.4	28.6	54.5	71.9
	339	2.6	4.1	10.1	27.8	48.1	64.9
Average		2.6	4.1	10.2	28.2	51.3	68.4
21.8	340	1.6	2.5	6.4	17.8	34.7	48.1
	341	1.7	2.6	5.9	16.3	31.1	41.2
Average		1.7	2.6	6.2	17.1	32.9	44.7

* = before/after thinning; T = thinned.

Table 21—Total net cubic-foot volume per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

		Total age and year					
Spacing treatment	Plot number	11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Cubic feet					
4.0	335	384	643	1,319	2,719	4,232	4,913
	350	265	464	1,092	2,629	4,367	5,405
Average		325	554	1,206	2,674	4,300	5,159
4.0, T	352	310	497	1,086	1,227	2,438	3,450
	353	419	638	1,249	1,213	2,490	3,708
Average		365	568	1,168	2,496/1,220*	2,464	3,579
7.4	331	140	242	665	1,799	3,346	4,451
	332	123	235	619	1,695	3,043	3,986
	342	133	230	640	1,806	3,275	4,100
	343	130	223	591	1,701	3,263	4,241
Average		132	233	629	1,750	3,232	4,195
7.4, T	344	123	218	632	1,284	2,558	3,641
	345	142	241	623	1,253	2,595	3,727
Average		133	230	628	1,803/1,269*	2,577	3,684
9.2	333	69	118	390	1,238	2,471	3,221
	334	77	132	335	1,025	2,019	2,533
Average		73	125	362	1,132	2,245	2,877
12.3	336	39	73	263	969	2,203	2,975
	337	40	72	231	785	1,829	2,585
	346	41	73	234	849	1,816	2,260
	347	40	71	210	727	1,585	2,133
	348	40	74	232	778	1,596	2,076
	349	41	73	213	733	1,641	2,288
Average		40	73	231	807	1,778	2,386
17.6	338	20	37	118	447	1,046	1,543
	339	21	39	117	434	922	1,388
Average		20	38	118	440	984	1,466
21.8	340	12	22	70	269	648	1,002
	341	13	22	62	244	574	850
Average		12	22	66	256	611	926

* = before/after thinning; T = thinned.

Table 22—Net Scribner board-foot volume per acre, trees 6 inches and larger, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet				Board feet			
4.0	335	0	0	0	672	2,352	4,564
	350	0	0	0	370	2,180	4,529
Average		0	0	0	522	2,266	4,547
4.0, T	352	0	0	0	60	1,242	3,646
	353	0	0	0	0	902	3,726
Average		0	0	0	30*	1,072	3,686
7.4	331	0	0	0	746	4,300	7,692
	332	0	0	3	539	3,203	5,935
	342	0	0	33	978	4,511	7,572
	343	0	0	43	539	3,571	6,710
Average		0	0	20	701	3,829	6,977
7.4, T	344	0	0	0	458	3,687	7,823
	345	0	0	0	576	3,666	7,596
Average		0	0	0	680/517*	3,677	7,710
9.2	333	0	0	0	322	2,972	5,844
	334	0	0	0	360	2,852	5,401
Average		0	0	0	341	2,912	5,623
12.3	336	0	0	0	405	4,435	8,064
	337	0	0	0	426	3,950	7,379
	346	0	0	0	409	3,650	6,065
	347	0	0	0	252	2,674	5,077
	348	0	0	0	364	3,140	5,552
	349	0	0	0	317	2,918	5,648
Average		0	0	0	362	3,461	6,298
17.6	338	0	0	0	290	2,342	4,585
	339	0	0	0	329	1,993	4,041
Average		0	0	0	310	2,168	4,313
21.8	340	0	0	0	165	1,447	3,021
	341	0	0	0	108	1,190	2,390
Average		0	0	0	137	1,319	2,706

Total age and year (column heads 11 1971 through 22 1982).

* = before/after thinning; T = thinned.

Table 23—Average annual tree diameter increment, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
Feet				Inches			
3	923	0.21	0.37	0.26	0.51	0.37	0.26
8	915	.37	.48	.55	.37	.28	.19
	916	.44	.55	.55	.44	.31	.34
Average		.41	.52	.55	.41	.30	.27
12	917	.36	.53	.65	.52	.42	.35
	918	.37	.72	.74	.60	.39	.35
Average		.37	.63	.70	.56	.40	.35
16	919	.47	.64	.77	.63	.48	.40
	920	.46	.57	.90	.70	.64	.48
Average		.47	.61	.84	.67	.56	.44
20	921	.44	.66	.92	.70	.60	.54
	922	.45	.67	.67	.60	.47	.54
Average		.44	.66	.80	.65	.54	.54

Total age and year of increment (column heads 12 1964 through 27 1978).

Table 24—Gross annual increment in basal area per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
		Total age and year of increment					
Feet		- - - - - Square feet - - - - -					
3	923	16.0	10.4	23.5	12.5	15.2	13.2
8	915	5.3	10.1	16.8	14.1	12.0	9.4
	916	7.4	14.3	21.0	20.8	16.5	15.8
Average		6.4	12.2	18.9	17.5	14.3	12.6
12	917	2.5	6.1	11.1	11.1	10.4	10.2
	918	3.4	9.9	16.6	17.4	12.9	13.3
Average		3.0	8.0	13.9	14.3	11.7	11.8
16	919	1.9	4.3	8.6	9.3	8.1	8.3
	920	2.2	3.7	8.9	9.6	10.2	9.4
Average		2.1	4.0	8.8	9.5	9.2	8.9
20	921	1.0	2.6	6.3	6.5	6.6	7.6
	922	1.1	2.4	3.9	4.8	4.3	6.5
Average		1.1	2.5	5.1	5.7	5.5	7.1

Table 25—Gross annual increment in cubic-foot volume per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
		Total age and year of increment					
Feet		- - - - - Cubic feet - - - - -					
3	923	362	333	762	550	675	606
8	915	59	152	345	408	440	537
	916	88	223	442	592	608	835
Average		74	188	394	500	524	686
12	917	29	82	212	290	322	424
	918	39	137	328	454	426	581
Average		34	91	270	372	374	503
16	919	21	55	154	232	243	349
	920	26	51	159	240	290	384
Average		24	53	157	236	267	367
20	921	10	30	103	151	184	272
	922	12	29	65	111	124	222
Average		11	30	84	131	154	247

Table 26—Gross annual increment in Scribner board-foot volume per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
		Total age and year of increment					
Feet		Board feet					
3	923	0	227	982	1,224	1,812	2,555
8	915	0	0	452	1,079	1,497	2,256
	916	0	31	732	1,921	2,316	3,793
Average		0	16	592	1,500	1,907	3,025
12	917	0	25	333	969	1,238	2,037
	918	0	0	727	1,652	1,761	2,885
Average		0	13	530	1,311	1,500	2,461
16	919	0	0	261	776	1,010	1,738
	920	0	0	349	939	1,255	1,945
Average		0	0	305	858	1,133	1,842
20	921	0	0	153	534	771	1,362
	922	0	4	89	331	465	1,070
Average		0	2	121	433	618	1,216

Table 27—Average annual tree diameter increment, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	11 1972	14 1975	17 1978	20 1981
		Total age and year of increment			
Feet		Inches			
4	335	0.38	0.25	0.18	0.11
	350	.34	.30	.23	.25
Average		.36	.28	.20	.18
4, T	352	.32	.29	.43	.40
	353	.29	.24	.41	.46
Average		.31	.26	.42*	.43
7.4	331	.44	.60	.41	.30
	332	.51	.54	.38	.27
	342	.42	.61	.40	.25
	343	.45	.60	.46	.31
Average		.45	.59	.41	.28
7.4, T	344	.46	.62	.77	.46
	345	.43	.54	.96	.51
Average		.45	.58	.87*	.48
9.2	333	.41	.63	.46	.50
	334	.44	.77	.56	.38
Average		.43	.70	.51	.44
12.3	336	.51	.85	.76	.57
	337	.48	.79	.69	.57
	346	.46	.79	.70	.53
	347	.46	.75	.60	.45
	348	.53	.77	.66	.49
	349	.43	.70	.65	.51
Average		.48	.78	.67	.52
17.6	338	.46	.73	.82	.67
	339	.47	.73	.70	.77
Average		.46	.73	.76	.72
21.8	340	.45	.83	.81	.80
	341	.44	.85	.86	.66
Average		.44	.84	.83	.73

* = excluding the effect of altering mean stand diameter by thinning; T = thinned.

Table 28—Gross annual increment, by spacing treatment, plot, and total age in basal area per acre, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of increment			
		11 1972	14 1975	17 1978	20 1981
Feet		- - - - - - - - Square feet - - - - - - - -			
4	335	20.6	20.4	16.9	11.5
	350	17.3	24.6	20.5	13.9
Average		19.0	22.5	18.7	12.7
4, T	352	15.7	20.5	14.4	16.7
	353	17.6	21.3	14.1	20.1
Average		16.7	20.9	14.3*	18.4
7.4	331	8.1	17.9	18.1	15.7
	332	9.3	16.8	16.4	12.6
	342	7.9	18.9	18.1	12.9
	343	7.7	17.0	18.9	15.9
Average		8.3	17.7	17.9	14.3
7.4, T	344	8.4	19.5	15.5	16.3
	345	8.4	17.9	16.2	18.5
Average		8.4	18.7	15.9*	17.4
9.2	333	5.3	13.8	14.9	15.1
	334	4.6	11.1	13.9	11.3
Average		5.0	12.5	14.4	13.2
12.3	336	3.4	11.2	16.2	15.1
	337	3.0	8.5	12.4	13.5
	346	3.1	9.5	13.9	11.0
	347	2.9	8.7	10.7	10.1
	348	3.2	8.5	11.4	9.7
	349	2.7	8.3	11.6	12.1
Average		3.1	9.1	12.7	11.9
17.6	338	1.5	4.6	8.1	9.0
	339	1.5	4.4	6.8	9.2
Average		1.5	4.5	7.5	9.1
21.8	340	1.0	3.0	4.9	6.8
	341	.9	2.9	4.6	5.1
Average		1.0	3.0	4.8	6.0

* = after thinning; T = thinned.

Table 29—Gross annual increment in cubic-foot volume per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	11 1972	14 1975	17 1978	20 1981
		Total age and year of increment			
Feet		Cubic feet			
4.0	335	259	408	524	562
	350	199	440	590	639
Average		229	424	557	601
4.0, T	352	187	399	362	527
	353	219	403	354	619
Average		203	401	358*	573
7.4	331	103	311	486	549
	332	112	291	444	453
	342	97	328	489	479
	343	93	294	498	548
Average		101	306	479	507
7.4, T	344	98	339	404	531
	345	102	305	418	588
Average		100	322	411*	560
9.2	333	56	222	359	466
	334	55	181	333	359
Average		56	202	346	413
12.3	336	34	175	353	443
	337	32	132	272	390
	346	33	148	304	330
	347	32	134	235	300
	348	36	134	253	290
	349	31	127	253	347
Average		33	142	272	350
17.6	338	17	72	175	249
	339	18	69	150	248
Average		18	70	162	249
21.8	340	10	47	100	172
	341	10	45	93	132
Average		10	46	97	152

* = after thinning; T = thinned.

Table 30—Gross annual increment in Scribner board-foot volume per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of increment: 11 1972	14 1975	17 1978	20 1981
Feet		Board feet			
4.0	335	0	59	405	1,025
	350	0	0	440	1,058
Average		0	30	423	1,042
4.0, T	352	0	0	161	1,073
	353	0	0	50	1,238
Average		0	0	106*	1,156
7.4	331	0	35	744	1,679
	332	0	39	648	1,208
	342	0	74	888	1,550
	343	0	52	727	1,578
Average		0	50	752	1,522
7.4, T	344	0	7	725	1,869
	345	0	76	701	1,969
Average		0	42	713*	1,919
9.2	333	0	0	426	1,498
	334	0	4	531	1,282
Average		0	2	479	1,390
12.3	336	0	0	914	1,864
	337	0	0	723	1,696
	346	0	0	741	1,354
	347	0	6	487	1,215
	348	0	0	627	1,177
	349	0	3	530	1,352
Average		0	2	670	1,443
17.6	338	0	0	481	1,076
	339	0	12	376	1,058
Average		0	6	429	1,067
21.8	340	0	0	253	746
	341	0	0	222	557
Average		0	0	238	652

* = after thinning; T = thinned.

Table 31—Average number of trees per acre, by diameter class, for spacing treatments and selected years, Cascade Head, Oregon

Diameter class	3-foot control, plot 923 (0.01998 acre)			8-foot spacing, plots 915-916 (0.09164 acre)			12-foot spacing, plots 917-918 (0.16528 acre)			16-foot spacing, plots 919-920 (0.29384 acre)			20-foot spacing, plots 921-922 (0.45914 acre)		
	1963	1971	1980	1963	1971	1980	1963	1971	1980	1963	1971	1980	1963	1971	1980
Inches	Number of trees														
1	1,952	551	--	196	--	--	60	--		34	--		44		
2	851	551	50	295	11	11	175	6		82	3		44		
3	751	450	300	98	66	22	67	12		48	--		22	2	
4	250	400	100	33	109	55	24	12		10	7			4	
5	150	250	300		66	44		30			14			11	
6	100	300	150		131	66		67	12		27			22	2
7		100	50		109	33		60	24		24	17		26	--
8		100	200		44	76		24	24		27	7		15	2
9		50	150		66	87		67	54		24	7		17	9
10			150		11	33		24	42		24	17		4	11
11			50		11	76		6	30		7	20		2	20
12						55			18			17			13
13						11			42			10			9
14						11			18			20			15
15						11			24			27			13
16						11			6			7			6
17									--			10			4
18									6						
Total trees	4,004	2,603	1,201	622	622	600	327	309	302	174	163	160	108	104	104
Total basal area	115	251	329	14.8	132	256	8.8	89	201	4.7	52	135	2.1	30	88

-- = no data.

Table 32—Average number of trees per acre, by diameter class, for spacing treatments and selected years, Clallam Bay, Washington

Diameter class	Absolute control, late thinned; plot 354 (0.01 acre)			4.0-foot control, plots 335-350 (0.034 acre)		4.0-foot control with late thinning, plots 352-353 (0.112 acre)			7.4-foot initial spacing; plots 331, 332, 341, and 343 (0.446 acre)		7.4-foot initial spacing, then thinned; plots 344-345 (0.336 acre)				9.2-foot initial spacing, plots 333-345 (0.105 acre)		12.3-foot initial spacing; plots 336, 337, 346, 347, 348, and 349 (0.784 acre)		17.6-foot initial spacing, plots 338-339 (0.340 acre)		21.8-foot initial spacing, plots 340-341 (0.606 acre)	
	1977		1983	1971	1983	1977		1983	1971	1983	1971	1977		1983	1971	1983	1971	1983	1971	1983	1971	1983
	Before thin	After thin				Before thin	After thin					Before thin	After thin									
Inches																						
1	9,400			1,394	--	474			282		319				200		73		38		25	
2	5,600	100		1,162	145	573	18		379		417	24	6		228		196		88		59	
3	1,400	300	100	116	203	618	98	9	110	27	104	107	21	3	57	19	18	4	15		7	
4	600	400	--	58	436	519	251	63	9	47	15	191	92	9	10	9		4				
5			200		378	269	197	63	2	94		209	134	21		0		17		6		
6			100		174	152	98	161		121		152	110	68		48		17		3		3
7			100		145	36	9	134		130		68	60	77		38		14		0		2
8			300		58			179		90		36	24	68		133		23		18		5
9				--	--			45		81				77		57		50		20		15
10					29			9		52				60		38		45		12		12
11					29					29				36		19		45		29		16
12										4				18		19		28		26		18
13										2				3				4		9		10
14																				9		2
Total trees 1/	17,000	800	800	2,731	1,598	2,641	672	662	782	677	885	787	447	441	495	382	287	249	141	132	91	83
Total basal area	271	52	172	38.3	230.5	159.1	72.2	168.5	15.2	192.6	15.6	110.3	72.6	167.2	8.7	140.1	5.2	117.9	2.6	79.7	1.6	50.4

1/ Because of differences in how plots were combined to get averages, the total number of trees may differ slightly from averages given in table 18.

Hoyer, Gerald E.; Swanzy, Jon D. Growth and yield of western hemlock in the Pacific Northwest following thinning near the time of initial crown closure. Res. Pap. PNW-365. Portland, OR: U.S. Department of Agriculture; Forest Service, Pacific Northwest Research Station; **1986**. 52 p.

Growth, stand development, and yield were studied for young, thinned western hemlock (*Tsuga heterophylla* Raf. [Sarg.]). Two similar studies were located at Cascade Head Experimental Forest in the Siuslaw National Forest, western Oregon, and near Clallam Bay on the Olympic Peninsula in Washington. At the latter, first thinnings were made at two ages; one at about the time of initial crown closure (early or crown-closure thinning) and the other after competition was well underway (late or competition thinning).

Stands, age 7 at breast height at time of crown closure thinning, were grown for 17 years at Cascade Head and for 11 years at Clallam Bay. In addition, 6 years after (early) crown-closure thinning the first (late) competition thinning was made at Clallam Bay on previously prepared, well-stocked stands. The tree spacing on the early thinnings ranged from 3 feet to 22 feet.

At ages 24 and 18 breast height on the two studies, stands with the most stocking produced the most cubic-foot volume and volume increment and the smallest average diameter. Early thinnings spaced between 7 and 12 feet produced the most usable wood in terms of Scribner board-foot volume of trees 6 inches in diameter and larger.

During the 6-year period following the late thinning, the treatments produced 55, 86, and 180 more cubic-foot volume increment per acre per year than did early thinnings that grew to the same basal area. The studies provide an approximation of the behavior of stands grown at given plantation spacings. The studies suggest that volume increment from stands thinned late differs from the volume increment of early thinning or planted stands that have attained basal area density similar to the late-thinned stands. Representative growth and yield data is provided for all treatments.

Keywords: Spacing thinnings, stand development, increment, yield (forest), western hemlock.

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